RESEARCH IN STOCHASTIC PROCESSES AND THEIR APPLICATIONS

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Justification	
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Distribution /	
Availability Codes	
Dist	Avail and / or Special
A-1	

Department of Statistics
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Chapel Hill, NC 27599-3260

Army Research Office Grant No. DAAL 03 92 G 0008

FINAL SCIENTIFIC REPORT

Period: 1 October 1992 through 30 May 1995

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	June 95	Final 1 Jan 92 - 31 May 95

4. TITLE AND SUBTITLE

Research in Stochastic Processes & Their Applications

5. FUNDING NUMBERS

DAAL03-92-G-0008

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Univ. of North Carolina
Chapel Hill, NC 27599-3260

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U.S. Army Research Office
P.O. Box 12211
Research Triangle Park, NC 27709-2211

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

ARO 29297.28-MA

11. SUPPLEMENTARY NOTES

The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (*Maximum 200 words*)

The research effort in stochastic processes has been a major part of the research activity organized by the Center for Stochastic Processes in the Statistics Department. This effort, involving permanent faculty, visitors and students, has developed in a very significant way under ARO support. Indeed, building on the work of the Center since its inception, the stochastic process activity has continued to attract wide interest and recognition in the international statistical community.

 (continued on reverse side)

14. SUBJECT TERMS	15. NUMBER OF PAGES
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

The main ingredients of the program are:

- Significant research interaction among the permanent faculty, the senior internationally recognized visitors, and the junior visitors – promising young researchers.
- The weekly Stochastic Processes Seminar which provides a regular forum for exchange of current research ideas among permanent and visiting staff as well as short term visitors.
- The Center for Stochastic Processes Technical Report series which contains the research produced by permanent and visiting staff, prior to publication in the scientific literature. Over 450 technical reports have been produced by the participants, involving research results in a wide area of stochastic process theory and applications.

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SUMMARY OF RESEARCH ACTIVITY

Research was conducted and directed in the area of stochastic processes and their applications in engineering, neurophysiology, oceanography , etc., by the principal investigators, S. Cambanis, G. Kallianpur and M.R. Leadbetter and their associates. A list of the main areas of research activity follows. More detailed descriptions of the work of all participants is given in the main body of the report.

Sampling designs for time series

Signal quantization

Wavelets, multiresolution decomposition, and random processes

Non-Gaussian stable models: Structure and inference

Periodically correlated processes and random fields

Lévy processes

Stationary random fields and their prediction

Isoperimetric inequalities

Infinite dimensional stochastic differential equations driven by Poisson random measures

Stochastic differential equation models for spatially distributed neurons

Propagation of chaos for interacting systems

Nonlinear stochastic analysis

Point processes, random sets, and random measures

Random measures associated with high levels

Tail inference for stationary sequences

Markov models of fatigue stresses

DESCRIPTION OF RESEARCH ACTIVITY

The research effort in stochastic processes has been a major part of the research activity organized by the Center for Stochastic Processes in the Statistics Department. This effort, involving permanent faculty, visitors and students, has developed in a very significant way under ARO support. Indeed, building on the work of the Center since its inception, the stochastic process activity has continued to attract wide interest and recognition in the international statistical community.

The main ingredients of the program are:

- Significant research interaction among the permanent faculty, the senior internationally recognized visitors, and the junior visitors – promising young researchers.
- The weekly Stochastic Processes Seminar which provides a regular forum for exchange of current research ideas among permanent and visiting staff as well as short term visitors.
- The Center for Stochastic Processes Technical Report series which contains the research produced by permanent and visiting staff, prior to publication in the scientific literature. Over 450 technical reports have been produced by the participants, involving research results in a wide area of stochastic process theory and applications.

More detailed descriptions of the work of the principal investigators, S. Cambanis [1], G. Kallianpur and M.R. Leadbetter and their associates are given in this report.

[1] Professor Cambanis died on April 12, 1995 after a prolonged illness. The description of his research for 1994-95 was prepared by G. Kallianpur.

Center Faculty

The work briefly described here was developed in connection with problems arising from and related to the statistical communication theory and the analysis of stochastic signals and systems.

Part I deals with questions raised by the observation of continuous time random signals at discrete sampling times, and the transmission or storage of analog random signals in digital form.

Part II considers non-Gaussian models frequently encountered in practical applications. The goal is to learn how Gaussian and linear signal processing methodologies should be adapted to deal with non-Gaussian regimes.

Part III studies wavelets and multiresolution analysis for random processes.

Part IV Completion of previous work with additional research.

I. DIGITAL PROCESSING OF ANALOG SIGNALS

Continuous time signals are typically sampled at discrete times and inferences are made on the basis of these samples, which may be further quantized (or rounded-off) for digital processing. Items 1–3 describe work in progress on the quantization of vector random signals, on the degradation of the performance of sampling designs due to quantization, and on general sampling approximations. Items 1 and 2 represent continuing work with former Ph.D. students K. Benhenni (Univ. of Grenoble) and Y. Su (Univ. of Arizona). Item 3 is in collaboration with G. Anastassiou (Memphis State Univ.).

1. Asymptotically optimal bivariate quantization. [1,2]

We first consider mean square distortion measure. For scalar random variables, optimal quantizers are known in several cases and also simple asymptotically optimal quantizers are known for all densities, as the number of representative points (levels of quantization) increases to infinity. When a bivariate random vector is uniformly distributed over the unit square, the asymptotically optimal quantizer corresponds to the tesselation of regular hexagons with the representative points at their centers. So far asymptotically optimal quantizers for nonuniformly distributed signals in two or higher dimensions are not known. For certain bivariate signals, we develop in [1] a quantizing method which is asymptotically optimal. Examples with Gaussian, Laplacian and multi-modal density functions are considered.

In [2] we consider an L_1 measure of distortion, and we characterize the performance of asymptotically optimal quantizers. We also develop a method of quantization which is asymptotically optimal for certain bivariate signals, and we consider specific examples of bivariate distributions.

2. The effect of quantization on the performance of sampling designs. [3]

The most common form of quantization is rounding-off, which occurs in all digital systems. A general quantizer approximates an observed value by the nearest among a finite number of representative values. In estimating weighted integrals of time series with no quadratic mean derivatives, by means of samples at discrete times it is known that the rate of convergence of the mean square error is reduced from n^{-2} to $n^{-1.5}$ when the samples are quantized (Bucklew and Cambanis (1988)). For smoother time series, with $k = 1, 2, \ldots$ quadratic mean derivatives, it is now shown that the rate of convergence is reduced from n^{-2k-2} to n^{-2} when the samples are quantized, which is a very significant reduction. The interplay between sampling and quantization is

also studied, leading to (asymptotically) optimal allocation between the number of samples and the number of levels of quantization.

3. General sampling approximations. [4]

A deterministic signal with finite energy and n derivatives, is approximated by means of its periodic samples with period 2^{-k} via a scaled filter. An nth order asymptotic expansion is developed for the resulting integrated square error, leading to general sampling approximations for nonbandlimited signals. This result has just been derived. Next the interplay between signal and filter will be studied, for improved quality of approximation, and stationary random signals will also be considered.

II. NON-GAUSSIAN MODELS

In continuing the exploration of non-Gaussian models we have studied the finiteness and form of the conditional variance when regressing on several jointly stable random quantities in Item 4, and we have characterized the linearity property of the regression of heavy-tailed autoregressive processes in reversed time in Item 5. Item 4 represents continuing work with S. Fotopoulos (Washington State Univ. and visitor to the Center in '92-93) which is being pursued in the direction of higher order conditional moments. Item 5 represents continuing work with I. Fakhre-Zakeri (Univ. of Maryland and visitor to the Center in 1993) which now explores autoregressive sequences of higher order.

Item 6 represents a substantial revision, with strengthening of the basic result and simplification of its proof, of work reported in earlier years joint with W. Wu (Univ. of Illinois and former Ph.D. student) and colleague E. Carlstein.

4. Multiple conditional variance on stable vectors. [5]

A remarkable property of jointly Gaussian random variables is that conditional variances are nonrandom (i.e. degenerate). For bivariate symmetric stable r.v.'s (that are not Gaussian) this is no longer the case; Wu and Cambanis (1991) derived necessary and sufficient conditions for the conditional variance to be finite, and showed that it has a universal functional form, independent of the joint distribution, and that the variance increases (unboundedly) with the increasing absolute value of the given r.v. In [4] we consider the conditional variance of one r.v. given n other r.v.'s, when they are jointly symmetric stable (and not Gaussian). Necessary and sufficient conditions are derived for the conditional variance to be finite, and its expression is obtained. When the n given r.v.'s are independent, the conditional variance is a sum of n universal functions each depending on one of the conditioned r.v.'s; these are multiples of the bivariate conditional universal variance function, but the coefficients not those appearing in the expression of the bivariate conditional variance, of which at most one may be finite! We also apply these results to certain stable processes, such as scale mixtures of Gaussian processes and harmonizable processes.

5. The prediction of heavy-tailed autoregressive sequences: Forward versus reverses time. [6]

The prediction of heavy-tailed first order autoregressive sequences is considered. In forward time the regression on all past values is the same as the one-step regression on the previous value, which is linear. In reversed time the regression on all future values is the same as the one-step regression on the immediate future value (i.e. the Markovian property is retained) and we show that it is linear if and only if the innovations have a semistable distribution. This answers a question posed by Rosenblatt (1992), who considered sequences with finite second moment and showed

that regression with time reversed is linear if and only if the innovations are Gaussian.

These results were first proven under finite absolute moments of order 1, and then extended appropriately to the case where the conditional absolute moment of order 1 is finite, enabling us to consider all possible values of the index of semistability.

When the distribution of the innovations is non-Gaussian stable, then both regressions in forward and reversed time are linear, but while the forward regression is the best linear predictor, the regression with time reversed is not! We find the best linear predictor with time reversed and we compare its performance with that of the simpler but inferior linear regression predictor for all values of the index of stability.

6. Bootstrapping the sample mean for data with infinite variance. [7]

When data come from a distribution belonging to the domain of attraction of a stable law, Athreya (1987) showed that the bootstrapped sample mean has a random limiting distribution, implying that the naive bootstrap could fail in the heavy-tailed case. The goal here is to classify all possible limiting distributions of the bootstrapped sample mean when the sample comes from a distribution with infinite variance, allowing the broadest possible setting for the (nonrandom) scaling, the resample size, and the mode of convergence (in law). The limiting distributions turn out to be infinitely divisible with possibly random Lévy measure, depending on the resample size. An averaged-bootstrap algorithm is then introduced which eliminates any randomness in the limiting distribution; the averaged-bootstrap converges to the correct (stable) limit in the case of heavy-tailed stable data, provided that appropriate sample-based adjustments have been made for the scale and skewness.

III. MULTIRESOLUTION DECOMPOSITION AND WAVELET TRANSFORMS OF RANDOM SIGNALS

The wavelet approximation of random signals at given resolution is considered in Item 7, which is a substantial generalization of earlier work. The properties of the wavelet transform of random signals are considered in Item 8. These represent continuing joint work with E. Masry (Univ. of California, San Diego) and C. Houdré (Stanford Univ. and visitor to the Center).

7. Wavelet approximation of deterministic and random signals. [8]

The multiresolution decomposition of deterministic and random signals and the resulting approximation at increasingly finer resolution is examined. Specifically, an nth order expansion is developed for the error in the wavelet approximation at resolution $2^{-\ell}$ of deterministic and random signals. The deterministic signals are assumed to have n continuous derivatives, while the random signals are only assumed to have a correlation function with continuous nth order derivatives off the diagonal – a very mild assumption. For deterministic signals square integrable over the entire real line, for stationary random signals over finite intervals, and for nonstationary random signals with finite mean energy over the entire real line, the smoothness of the scale function can be matched with the signal smoothness to improve substantially the quality of the approximation. In sharp contrast this is feasible only in special cases for nonstationary random signals over finite intervals and for deterministic signals which are only locally square integrable.

8. Continuous wavelet transforms of random processes. [9]

Some second order properties of random processes such as periodic correlation, stationarity, harmonizability, self-similarity, are characterized via corresponding properties of their wavelet transform: Anyone of these properties of the wavelet transform

characterizes the corresponding property of the increments of the random process, of order equal to the order of regularity of the analyzing wavelet.

IV. Completion of previous work with additional research

During the last year of his life, Professor Cambanis's research in collaboration with various Center visitors was brought to a final form. Here is a brief description.

1. (with Y.Z. Hu) Exact convergence rate of the Euler–Maruyama schemes with application to sampling design [10]

A regular partition $\pi_n(h)$ of the interval $[0,T]$ is a partition $\{t_i\}$ such that $t_0 = 0$ and $\int_{t_k}^{t_{k+1}} h(s)ds = \frac{1}{n}$, $k = 1, \ldots, n-1$ where h is a continuous positive density on $[0,T]$. Let x_t be the solution of the stochastic differential equation
$x_t = x + \int_0^t b(x_s)ds + \int_0^t a(x_s)dw_s, \quad 0 \le t \le T,$
a, b being real valued functions on $\mathbf{R}$ with bounded derivatives and w_t is a canonical Wiener process. Let x_t^π be the approximate solution of the SDE, using the Euler–Maruyama scheme corresponding to a regular partition $\pi_n(h)$.

The limit

$$\lim_{n\to\infty} n \int_0^t E|X_t - X_t^{\pi_n(h)}|^2 dt$$

is calculated as a functional of the sampling density h and the parameters of the SDE. The "best" sampling density and the best way is found of discretizing regularly the interval for integrated mean square approximation error. The linear case is also considered in detail.

2. (with I. Fakhre-Zakeri) Forward and reversed time prediction of autoregressive (AR) schemes [11].

It is shown that the best predictor with time reversed is linear if and only if the innovations are Gaussian. This is an extension to AR sequences of general order of M. Rosenblatt's 1993 result for AR schemes of order one.

3(a) (with S. Fotopolous) Conditional variance for stable random vectors [12]

A necessary and sufficient condition is found for the conditional variance $\mathrm{Var}(X_{n+1}|X_1, \ldots, X_n)$ to be finite where $(X_1, \ldots, X_n, X_{n+1})$ is an α–stable random vector $(1 < \alpha < 2)$ with spectral measure Γ. The condition is given in terms of Γ.

(b) Conditional variance for scale mixtures of normal distributions.

An n–vector random variable X is a scale mixture of a normal distribution if $X \stackrel{d}{=} A^{1/2}G$ where A is a positive random variable independent of the n–column normal vector G with mean 0 and positive definite covariance matrix, the equality being in distribution.

A motivation for studying this problem is the important example where the distribution of A is totally right skewed $\alpha/2$–stable $(0 < \alpha < 2)$ with Laplace transform $E\exp(-uA) = \exp(-u^{\alpha/2})$, $u \ge 0$. $EA^p < \infty$ if and only if $p < \alpha/2$. Then X has a multivariate symmetric α–stable distribution and in view of the independence of A and G, the components of X have finite absolute moments of order $< \alpha$ only. Their second moment is always infinite and so is their first absolute moment when $0 < \alpha \le 1$.

The main result obtained is that scale mixtures of normal distributions have linear regressions but that their conditional variances are not constant. Results on the finiteness of absolute moments of suitably defined components of X are also obtained.

Let $X = (X_1, X_2)$ be a random vector distributed over a region D in the plane R^2 according to a known probability density function $p(x), x \in D$. For a fixed positive integer N, consider a partition of D into N disjoint subregions $D_{i,N}$, $i = 1, \ldots, N$, whose union is D: $D = \cup_{i=1}^{N} D_{i,N}$, select a representative point $x_{i,N}$ from each region $D_{i,N}$ and define the quantizer function

$$Q_N(x) = \sum_{i=1}^{N} x_{i,N} 1_{D_{i,N}}(x), \quad x \in D,$$

where $1_{D_{i,N}}(\cdot)$ denotes the indicator function of the set $D_{i,N}$. The quantizer $Q_N(\cdot)$ maps (or rounds off) every point in $D_{i,N}$ to the representative point $x_{i,N}$. The random vector $X = (X_1, X_2)$ is assumed to have finite second moment: $E \parallel X \parallel^2 < \infty$, where $\parallel x \parallel = (x_1^2 + x_2^2)^{1/2}$ is the Euclidean distance, and the performance of the quantizer is measured by the mean square error (mse)

$$(1) \qquad \begin{aligned} e^2(Q_N, p) &\equiv E \parallel X - Q_N(X) \parallel^2 = \int_D \parallel x - Q_N(x) \parallel^2 p(x) dx \\ &= \sum_{i=1}^{N} \int_{D_{i,N}} \parallel x - x_{i,N} \parallel^2 p(x) dx. \end{aligned}$$

The minimizer Q_N° of $e^2(A_n, p)$ over all quantizers Q_N with N representative points is called the optimal quantizer.

In this work a quantizing method is given which is asymptotically optimal. Examples of simulations with Gaussian, Pearson Type VII and Laplacian density functions are considered.

(with K. Podgorski and A. Weron) Chaotic behavior of infinitely divisible processes [13]

In this paper, the hierarchy of chaotic properties of symmetric infinitely divisible stationary processes is studied in the language of their stochastic representation. The structure of the Musielak–Orlicz space in this representation is exploited here.

(with G. Anastassiou) Non–orthogonal wavelet approximation with rates of deterministic signals [14]

An nth order asymptotic expansion is produced for the L_2–error in an non–orthogonal (in general) wavelet approximation at resolution 2^{-k} of deterministic signals f. These signals over the whole real line are assumed to have n continuous derivatives of bounded variation. The engaged non–orthogonal (in general) scale function φ fulfills the partition of unity property and it is of compact support. The asymptotic expansion involves only even terms of products of integrals involving φ with integrals of squares of (the first $[\frac{n}{2}] - 1$ only) derivatives of f.

(with C. Houdré). On the continuous wavelet transform of second order random measures ([15], revised)

Some second order properties of random processes such as periodic correlation, stationarity, harmonizability, self–similarity, are characterized via corresponding properties of their wavelet transform: Anyone of these properties of the wavelet transform

characterizes the corresponding property of the increments of the random process, of order equal to the order of regularity of the analyzing wavelet. These results are then specialized to fractional Brownian motion and other self-similar processes.

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GOPINATH KALLIANPUR

The major areas of research have been the following:

I. Stochastic differential equations in infinite dimensional spaces and stochastic partial differential equations (SPDE)

II. Nonlinear stochastic analysis.

III. Nonlinear filtering theory.

IV. Prediction theory of second order random fields.

V. Periodically correlated (PC) processes and random fields.

I. SDE's IN INFINITE DIMENSIONAL SPACES AND SPDE's

1. (with J. Xiong) Existence and uniqueness of solutions [1]

The first phase of this work begun earlier with G. Hardy and S. Ramasubramanian was devoted to the existence and uniqueness of solution of nuclear space valued SDE's driven by Poisson random measures.

The existence of a weak solution is obtained by the Galerkin method. For uniqueness, a class of ℓ^2-valued processes which are called Good processes is introduced. An equivalence relation is established between SDE's driven by Poisson random measures and those by Good processes. The uniqueness is established by extending the Yamada–Watanabe argument to the SDE's driven by Good processes. This is an extension to discontinuous infinite dimensional SDE's of work done by G. Kallianpur, I. Mitoma and R. Wolpert [19] for nuclear space valued diffusions.

2. (with J. Xiong) Diffusion approximation of nuclear space-valued stochastic differential equations driven by Poisson random measures [2]

It is proved that, under suitable conditions, limits of Poisson random measure driven nuclear space valued SDE's are characterized by diffusion equations of the kind studied by Kallianpur, Mitoma and Wolpert. Applications to (i) stochastic models of environmental pollution and (ii) reversal potential models of neuronal behavior are discussed.

3. (with J. Xiong) Stochastic models of environmental pollution [3]

We study several stochastic models arising from environmental problems. First, we study the pollution in a domain where undesired chemicals are deposited at random times and locations according to Poisson streams. Incorporated with drift and dispersion, the chemical concentration can be modeled by linear stochastic partial differential equations (SPDE) which are solved by applying our general results SDE's in infinite dimensions.

We examine in a somewhat more general context, the stochastic dynamic model considered by Kwakernaak and by Curtain, and look at the problem in the framework of general SPDE's. Let

$$x \in \chi = [0, \ell]^d, \quad x = (x_1, \dots, x_d).$$

The underlying deterministic PDE is

$$\frac{\partial u}{\partial t} = D\Delta u - V. \bigtriangledown u + \alpha u, t > 0,$$

where $u = u_t(x), D > 0, V = (V_1, \ldots, V_d)$ and α are constants,

$$\Delta = d - \text{ dimensional Laplacian and } \nabla = \left(\frac{\partial}{\partial x_1}, \frac{\partial}{\partial x_2}, \ldots, \frac{\partial}{\partial x_d}\right).$$

Let

$$c_i = \frac{V_i}{2D_i}, \rho(x) = e^{-2(c_1x_1+\ldots+c_dx_d)} \quad \text{and} \quad H_0 = L^2(\chi, \rho(x)dx).$$

The cases $d = 1, 2$ or 3 are of physical interest,

$$d = 1 \quad \text{River Pollution,} \quad d = 2(\text{ or } 3) \quad \text{(Atmospheric Pollution).}$$

We impose the (Neumann) boundary conditions (for $d = 2$ or 3).

4. (with J. Xiong) Asymptotic behavior of a system of interacting stochastic differential equations driven by Poisson random measures [4]

We study a system of interacting stochastic differential equations taking values in nuclear spaces and driven by Poisson random measures. We also consider the McKean–Vlasov equation associated with the system. We show that under suitable conditions the system has a unique solution and the sequence of its empirical distributions converges to the solution of the McKean–Vlasov equation when the size of the system tends to infinity. The results are applied to the voltage potentials of a large system of neurons and a law of large numbers for the empirical measure is obtained.

5. (with J. Xiong) Large deviations for infinite dimensional SDE's and SPDE's. [5]

This work generalizes the large deviation principle (LDP) to infinite dimensional SDE's. Large deviation results have been obtained for random fields $X^\epsilon(t, q), \quad t \geq 0, \quad q \in \mathcal{O}$, a bounded domain in $\mathbf{R}^d$ with regular boundary where X^ϵ is a space–time continuous **random field** which is the unique solution of an SPDE driven by space–time white noise. For $d = 1$, these results yield the LDP for stochastic reaction–diffusion equations. J. Xiong has considered a more abstract problem of theoretical value: LDP for diffusion processes in duals of nuclear spaces.

6. (joint work with Dr. Yaozhong Hu) Singular infinite dimensional SDE's and stochastic quantization [6]

A direct probabilistic approach to the so–called Parisi–Wu quantization of euclidean $P(\Phi)_2$–field theory was attempted unsuccessfully by G. Jona–Lasinio and P.K. Mitter. Later attempts have used the theory of Dirichlet forms. We have succeeded in carrying through the probabilistic approach and proved the Jona–Lasinio–Mitter result as a special case of a class of singular SDE's in duals of nuclear spaces. The results are being written up for publication.

7. (with A.G. Bhatt, R.L. Karandikar and J. Xiong) On interacting systems of Hilbert space valued diffusions [7]

A nonlinear Hilbert space valued stochastic differential equations where L^{-1} (L being the generator of the evolution semigroup) is not nuclear is investigated. Under the assumption of nuclearity of L^{-1}, the existence of a unique soltuion lying in the Hilbert space H has been shown by Dawson in an early paper. When L^{-1} is not nuclear, a solution in most cases lies not in H but in a larger Hilbert, Banach or

nuclear space. Part of the motivation of the present paper is to prove under suitable conditions on the coefficients that a unique strong solution can still be found to lie in the space H itself. A weak solution is obtained and its uniqueness is proved.

II Nonlinear stochastic analysis

(a) (with G. W. Johnson) Remarks on the existence of k–traces [8]

In making the work of Y.Z. Hu and P.A. Meyer rigorous, Johnson and Kallianpur had defined various types of Hilbert space valued k–traces [9]. Sufficient condition under which the limiting k–traces $\overrightarrow{Tr}^{k} f_p$ as well as the other three types of traces exist were obtained.

Operator valued multiple stochastic integrals

During a more recent visit of Professor Johnson to the Center, we became interested in developing the theory of operator valued multiple Wiener integrals. We have been able to define operator valued Wick exponentials. There are possible applications to Quantum Physics. The work is still continuing. A technical report is being prepared.

(b) (with A. Budhiraja) In this collaboration, several issues concerning multiple stochastic integrals were investigated – their connections with asymptotic statistics, anticipative calculus and nonlinear filtering. The last named work will be described under nonlinear filtering.

1. Multiple Stratonovich integrals with statistical applications

Hilbert space valued traces and multiple Stratonovich integrals with statistical applications [10]

Multiple Stratonovich integrals have been introduced and a new definition of Hilbert space–valued traces has been given which has made it possible to (a) derive the asymptotic distribution of V–statistics, and (b) derive two versions of Filippova's result on the asymptotic distribution of von Mises statistical functionals. This paper will appear in a special issue of PMS dedicated to the 100th birth anniversary of Jerzy Neyman and was presented by Kallianpur at the conference in Warsaw (November 1994).

2. Multiple Ogawa integrals, multiple Stratonovich integrals and the generalized Hu–Meyer formula [11]

Multiple Stratonovich integrals for non random kernels have been studied by Johnson and Kallianpur. In this work a theory of Hilbert space valued traces was also developed and a formula connecting the MSI with the MWI via these traces was derived. This formula was obtained in a rather heuristic fashion by Hu and Meyer [9] and is referred to as the Hu-Meyer formula. Multiple stochastic integrals of random integrands are of interest in problems concerning random fields. With this motivation we undertook an extension of multiple Wiener integrals and multiple Stratonovich integrals to the case of random kernels. This study also led to the developing of a theory for Hilbert space valued traces of random kernels. A generalization of the Hu-Meyer formula to the case of random kernels was obtained. The connections of these integrals with the Ogawa integral were also investigated.

3. Two results on multiple Stratonovich integrals [12]

Formulae connecting multiple Stratonovich integrals with single Ogawa and Stratonovich integrals are derived. Multiple Riemann–Stieltjes integrals with respect to certain smooth approximations of the Wiener process are considered and it is shown that these integrals converge to multiple Stratonovich integrals as the approximation converges to the Wiener process.

(c) (with R.L. Karandikar) Nonlinear transformations of the canonical Gauss measure on Hilbert space and absolute continuity [13]

The question of when a nonlinear transformation of the Wiener measure μ is absolutely continuous with respect to μ is a difficult problem that has been outstanding since the time of Cameron and Martin who were the first to investigate it. The most important work since then has been done by R. Ramer and generalized by S. Kusuoka.

A nonlinear theory of white noise on Hilbert space developed by R.L. Karandikar and myself has provided a new way to approach this problem.

The papers of R. Ramer (1974) and S. Kusuoka (1982) investigate conditions under which the probability measure induced by a nonlinear transformation on abstract Wiener space (γ, H, B) is absolutely continuous with respect to the abstract Wiener measure μ. These conditions reveal the importance of the underlying Hilbert space H but involve the space B in an essential way. The present paper gives conditions solely based on H and takes as its starting point a nonlinear transformation $T = I + F$ on H. New sufficient conditions for absolute continuity are given which do not seem easily comparable with those of Kusuoka or Ramer but are more general than those of Buckdahn (1991) and Enchev (1991). The Ramer-Itô integral occurring in the expression for the Radon-Nikodym derivative is studied in some detail and, in the general context of white noise theory, it is shown to be an anticipative stochastic integral which, under a stronger condition on the weak Gateaux derivative of F, is directly related to the Ogawa integral.

III. Nonlinear Filtering Theory

1. Stochastic filtering: a part of stochastic nonlinear analysis [14]

The purpose of this article which will appear in *Proceedings of the Norbert Wiener Centenary Conference*, Michigan State University (1994) is two-fold: to indicate in general terms, how nonlinear filtering theory, while considerably generalizing the techniques available to him, has remained faithful to Wiener's ideas; and to present some of the most recent results in stochastic filtering theory obtained in collaboration with Professors A. Bhatt, A. Budhiraja and R.L. Karandikar.

2. (with A. Bhatt and R.L. Karandikar) Uniqueness and robustness of solution of measure valued equations of nonlinear filtering [15]

The uniqueness of the solution of the Zakai equation is considered in the case when the signal process is a Markov process taking values in a complete, separable, metric space. Uniqueness was shown for the measure valued Zakai and Kushner–FKK equations. A robustness result was obtained and applications to the case when the signal is a solution of an SPDE were discussed.

For the independent signal and noise case, a robustness result (with convergence in probability) for the conditional distribution has also been obtained. The uniqueness result generalizes all previously known results and is of practical importance: We can now consider signal processes that are solutions of SPDE's – such processes occur in oceanographic problems. An application to the case where the signal is a "pollution"

process is completely worked out.

3. (with A. Budhiraja) Approximations to solutions of Zakai equations using multiple Wiener and Stratonovich expansions [16]

In the nonlinear filtering model

$$dY_t = h(X_t)dt + dB_t, \quad 0 \le t \le T$$

the signal is taken to be the solution of the SDE

$$dX_t = b(t, X_t)dt + a(t, X_t)dW_t$$

where $a, b \in C_b^{1,\infty}([0,T] \times \mathbf{R})$ and W and B are independent Wiener processes.

When the initial density exists and is in C_b^∞, the conditional density $u(t,x)$ exists and satisfies the SPDE

$$du(t,x) = \mathcal{L}(t)^* u(t,x)dt + h(t,x)a(t,x)dY_t$$

where $\mathcal{L}(t)^*$ is the formal adjoint of

$$\mathcal{L}(t)f(x) := \frac{1}{2}a^2(t,x)f''(x) + b(t,x)f'(x).$$

Let P_0 denote the measure equivalent to the original probability P such that Y_t is a Wiener process on $(\Omega, \mathcal{F}_t^Y, P_0)$. We obtain an $L^2(P_0)$–convergent chaos expansion for $u(t,x)$ in terms of multiple Wiener integrals $I_p[f_p(t,x|\ldots)]$. Further a system of integro–differential equations for the kernels f_p is obtained. We show that this system has a unique solution which is explicitly calculated. The resulting expansion for $u(t,x)$ is analogous to the expansions derived by Krylov and Veretennikov and by Kunita in somewhat different contexts.

The expansion is used (by double truncation) to obtain approximate solutions to the Zakai equation. The error bound is of the same order of magnitude as in the work of other authors. We are hoping to improve upon it.

IV. (with J. Farshidi and V. Mandrekar) Prediction Theory of Stationary Random Fields

The prediction problem for horizontal (and verttical) past has been solved. In the following paper now ready for publication, we obtain the spectral form of the two–fold Wold decomposition and establish necessary and sufficient conditions in terms of the spectral distribution to achieve the autoregressive expansion of the linear predictors.

Spectral characterization and autoregressive expansion of horizontal and vertical linear predictors for stationary second order random fields [17]

The principal problems considered are the spectral characterization of the linear predictors with respect to horizontal and vertical pasts (half planes) of a statonary second order random field (SSORF), and their autoregressive expansions (AR-expansions). The paper develops the notions of horizontal and vertical optimal factors, presents the spectral form of the two-fold Wold decomposition, and establishes necessary and sufficient conditions, as well as sufficient condition in terms of the spectral distribution, to achieve the AR-expansion of the linear predictors.

V. (with H. Hurd) Periodically Correlation (PC) Processes and Random Fields

In the paper, **Periodically correlated processes and their relationship to $L_2[0,T]$–valued stationary sequences** [18] we examine the ramifications of the natural unitary operator that is associated with periodically correlated processes. We show how this operator clarifies the spectral theory and representations that have been previously given for quadratic mean–continuous PC processes, and use it to obtain a Wold decomposition for these processes. By using a weaker sense of periodicity we extend the notion of PC processes to the $L_2[0,T]$–PC processes, a class that includes processes that may not be continuous in quadratic mean, such as $f(t)a(t)$ where $f(t)$ is a scalar $L_2[0,T]$ periodic function and $a(t)$ is wide sense stationary and continuous in quadratic mean. We obtain representations for the $L_2[0,T]$–PC processes that correspond to those obtained for the quadratic mean–continuous case, and show the relationship between them and the $L_2[0,T]$–valued stationary sequences.

The generalization of this work to PC **random fields** is now being investigated. There are two possible definitions: A second order mean zero process X is

(i) strongly PC random field if there exist numbers $T_1 > 0, \quad T_2 > 0$ such that the covariance

$$EX(u_1,v_1)\overline{X(u_2,v_2)} \equiv R(u_1,u_2,v_1,v_2) = R(u_1+kT_1,u_2+\ell T_2,v_1+kT_1,v_2+\ell T_2)$$

for all u_1,u_2,v_1,v_2 and k,ℓ,
(ii) weakly PC random field if $k=\ell=1$ in the above definition.

The structure theory and time domain analysis based on the paper of Kallianpur, Miamee and Niemi is the next important topic to be developed. The theory which we propose to develop can be applied to problems connected with meteorological processes which are perturbed by the effects of the rotation of the earth and noise processes of extraneous origin.

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M. ROSS LEADBETTER

Together with S. Cambanis and G. Kallianpur, M.R. Leadbetter provided continuing direction and participation in the research activities of the Center for Stochastic Processes. His work has emphasized (a) the development of theory for the description of extremal properties of stochastic processes and (b) their application to problems of oceanography, reliability of ocean structures, and the environment. A brief activity report is provided here – details are given in specific grant reporting. The activities are described by area as follows:

(a) Theory and methods

1. Dependent central limit theory and its ramifications.

A major theme for the current activity period is the development and use of specific convergence theory for dependent array sums. In particular normal and Compound Poisson convergence limits have been considered and classical criteria extended to deal conveniently with the latter case. The work has been particularly focussed towards two applications:

(a) High level exceedance modeling.

Measures of exceedance of a level by a stationary process have important application in environmental, oceanographic and other fields. Simple and useful examples are the time spent above a level, the area cut off above the level and (see 8 below for specific applications).

For very high levels (corresponding to fast rates of increase in limit theorems) Compound Poisson models apply, whereas more moderate levels (slower rates of increase) yield normal limits, and hence normal models. This work has been reported in [1] and [2].

(b) Tail inference for stochastic sequences

Previously reported work in [3] concerned estimation of parameters of exponential and regularly varying tails. The essential features of this work have been extracted and developed to give a more general and comprehensive theory which does not rely on the particular tail assumptions. Estimation procedures have been developed for the parameters (e.g. means and variances) required for the use of the normal modeling under (a).

2. Long range dependence in stationary processes.

Various long range dependence restrictions play pivotal roles in fields such as central limit theory and extreme value theory for stochastic sequences and processes. In particular the so called "strong mixing" condition and its variants are central to much of the theory. Some special topics are being investigated relative to its use and its verification – which can be a difficult problem. Its relevance to the strong law of large numbers is discussed in [4] and covariance conditions which imply strong mixing of exceedance measures for Gaussian processes, are being investigated.

3. Exceedance and excursion random measures.

An "exceedance random measure" is simply the amount of time a level is exceeded by a process in given (arbitrary) time sets. Its limiting behavior determines the asymptotic distribution of the process maximum, and more complex extremal properties are obtained by considering vectors of such exceedance random measures for different levels. This is explored in [5] and [6] both in general and for specific classes of processes.

Many works have investigated the limiting behavior of the two point process in the plane formed by plotting the (normalized) values of a stationary sequence. Work has continued (with T. Hsing) on a corresponding theory for continuous time stationary processes involving the "excursion random measure". This work, reported in [7], provides a comprehensive theorem summarizing many continuous time extremal results in a single statement.

4. Behavior of crests and troughs in random waves.

The successive crests and troughs in random waves provide an essential ingredient in discussion of fatigue failure of materials under random loads. The description of the work of I. Rychlik indicates the usefulness of Markov modeling for crests and troughs. In basic modeling Rychlik and Leadbetter are studying the properties of so-called "rainflow cycles" which are useful in describing "wave properties" of highly irregular sample functions often used in modeling of stress.

5. Extreme value theory for random fields

It is recognized (at least in statistical folklore) that at least variants of known results for extremes of stochastic processes must apply to random fields. A specific study of such problems has been undertaken in the current reporting period. This indeed confirms that extensions of the one dimensional theory are possible. However while a similar general approach is used, the greater geometrical complexity of random fields require changes of technique which prove interesting in themselves.

Two main areas have been investigated.

(i) Theory leading to the extremal types theorem and Poisson results for high values, being reported in [8].

(ii) An appropriate version of central limit theory along the lines of applying to measures of high level excursions by random fields. This will be reported in [9], currently under preparation.

(b) Applications Methods developed are being applied in naval oceanography and environmental studies as follows.

6. Ocean wave modeling

Gaussian modeling is often used for describing the ocean surface. This is often more appropriate for deep rather than shallow water cases where significant departures from Gaussian assumptions may occur. However even in such cases the Gaussian model may provide good results for specific purposes – such as the description of quantities such as wavelength and wave amplitude.

The adequacy of Gaussian models has been studied in this context in [10] with reference to both U.S. and European ocean wave data. In this study methods have been developed for the fitting of *functions* of Gaussian processes and compared with the Gaussian model itself for the cases in which the latter are inadequate. In particular it is demonstrated that functions of Gaussian processes can provide excellent models

for description of certain wave structure parameters.

7. Mine detection

The general considerations developed in (5) are applied in [11]. In this work, the acoustic reflectivity of the ocean floor is modeled as a stationary Gaussian field. Misclassification properties of general sonar mine detection systems are under these Gaussian assumptions and a rather detailed discussion given for false alarm rates. The evaluation of detection probabilities is more dependent on specific classes of mine and an illustrative example is given of the type of calculation required.

8. Environmental applications – stratospheric ozone regulation.

Work with a graduate student (L-S. Huang) continued on the application of exceedance methods to environmental and oceanographic data. The exceedance models in (1a) have been applied to environmental criteria for (ground level) ozone control. These involve the current "expected exceedance" ozone standard, and two proposed standards ("Area over threshold" and "SUM06") related to areas above regulatory levels (see [12]). Actual numerical studies have been made for ozone levels in Philadelphia, being reported in [13], along with relevant theory.

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Center Visitors

KARIM BENHENNI

Dr. Karim Benhenni of the University of Grenoble (formerly a Ph.D. student here) visited the Center for one month during August 1993 and worked on problems of sampling designs for time series.

1. (with S. Cambanis) The effect of quantization on the performance of sampling designs. [1]

This was reported under Cambanis's section.

2. Approximations and designs for estimating regression coefficients of independent stochastic processes. [2]

The problem of estimating the regression coefficients of a linear model for N independent stochastic processes $Y_i, i = 1, \ldots N$ is considered. The time integrated least square estimators depend on a random integral and thus are hard to compute in practice. Optimal approximations of these estimators are given, which depend on the inverse of the covariance matrix generated by the observations of the process at a finite number of points of a regular sampling design, and thus are unstable and not robust. Simple nonparametric approximations based on an adjusted trapezoidal rule using regular sampling designs are derived. The estimators obtained from the two approximations are unbiased, consistent and asymptotically jointly normal. For processes $Y_i, 1, \ldots, N$, having K quadratic mean derivatives, $K = 0, 1, 2 \ldots$, exact rates of convergence of the mean square error are derived along with asymptotically optimal designs.

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[2] K. Benhenni, Approximations and designs for estimating regression coefficients of independent stochastic processes, UNC Center for Stochastic Processes Technical Report No. 411, Dec. 93.

Dr. Abhay Bhatt, from the Indian Statistical Institute, Delhi, visited the Center from September 1993 through June 94.

1. (with G. Kallianpur, R.L. Karandikar and J. Xiong) On interacting systems of Hilbert space valued diffusions [1]

This was reported under Kallianpur's section.

2. (with G. Kallianpur and R.L. Karandikar) Uniqueness and robustness of solution of measure valued equations of nonlinear filtering [2]

This was also reported under Kallianpur's section.

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SERGE G. BOBKOV

Dr. Serge Bobkov of Syktyvkar State University in Russia visited the Center for four months during April - July 1993. He worked on isoperimetric inequalities for Gaussian and other mutlivariate distributions.

An isoperimetric problem for product probability measures with respect to a uniform enlargement is considered as follows. To each measurable set corresponds some larger set which is called its enlargement. To solve the isoperimetric problem, one minimizes the probability of the enlargement keeping the probability of the set constant. Very often, the enlargement is constructed with the help of a metric: the open h-neighbourhood of the set serves as its enlargement. Then, the isoperimetric problem can also be defined as follows: What is the maximal probability of the event that the deviation of a Lipschitz function from its quantile of a fixed order is more than a fixed number h? The answer to such a question is usually formulated as an (isoperimetric) inequality for the deviations.

1. Isoperimetric problem for uniform enlargement. [1]

Assume that the isoperimetric problem in the marginal metric space, equipped with a probability measure, has been solved. The question is how to solve the isoperimetric problem in the infinite product space equipped with the product measure and the uniform metric, which is defined as maximal distance between the coordinates of two points. An answer to this question is obtained in terms of the solution of the one-dimensional isoperimetric problem. In particular, necessary and sufficient conditions have been found, under which the exact one-dimensional isoperimetric inequality does not differ from the multidimensional one. The standard Gaussian and exponential distributions are considered as illustrations.

2. Extremal properties of half-spaces for log-concave distributions. [2]

The isoperimetric problem for log-concave product probability distributions for the supremum distance in $\mathbf{R}^n$ is considered. Necessary and sufficient conditions under which one-dimensional half-spaces are extremal are obtained.

3. A functional form of the isoperimetric inequality for the Gaussian measure. [3]

For the standard Gaussian measure on $\mathbf{R}^n$, it is shown that the isoperimetric property is equivalent to the following inequality:

$$\phi(\Phi^{-1}(Eg)) - E\phi(\Phi^{-1}(g)) \leq E|\nabla g|$$

for all smooth functions g on $\mathbf{R}^n$. Here Φ^{-1} is the inverse of the one dimensional standard normal distribution Φ with density φ.

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WLODZIMIERZ BRYC

Dr. W. Bryc (of the University of Cincinnati) spent January - May 1994 as a visitor to the Center. He conducted research in a variety of topics including specific questions concerning dependence structure involving correlations. His report [1] on this work relates to applications to tomography and is summarized as follows.

1. Conditional moment representations for dependent random variables [1]

We consider which sequences of random variables can be represented as conditional expectations of a fixed random variable with respect to a given sequence of σ-fields. This is the inverse problem that was studied by a number of authors in relation to alternating conditional expectations (ACE) of generalized additive models and algebraic reconstruction techniques of tomography. This note studies the "population" variant of the problem without reference to the estimation of conditional expectations involved. The goal is to present sufficient conditions for the solvability, which then might form the basis for numerical analysis. At present, this is well understood for two σ-fields and p-integrable random variables in the range $1 < p < \infty$. We study how much progress along similar lines can be achieved for finite and infinite families of σ-fields. The latter is of interest in nonlinear time series modeling. For finite families, explicit inequality equivalent to solvability is stated; sufficient conditions are given, and related explicit expansions are presented.

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[1] W. Bryc, Conditional moment representations for dependent random variables, UNC Center for Stochastic Processes Technical Report No. 423, Feb. 94.

AMARJIT BUDHIRAJA

Dr. Budhiraja visited the Center during July 1994 through June 1995 and worked on the following technical reports.

1. (with G. Kallianpur) Hilbert space valued traces and multiple Stratonovich integrals with statistical applications [1]
This work was reported under Kallianpur.

2. (with G. Kallianpur) Multiple Ogawa integrals, multiple Stratonovich integrals and the generalized Hu–Meyer formula [2]
This work was reported under Kallianpur.

3. (with G. Kallianpur) Approximations to the solution of the Zakai equation using multiple Wiener and Stratonovich expansions [3]
This work was reported under Kallianpur.

4. (with G. Kallianpur) Two results on multiple Stratonovich integrals [4]
See [12] under Kallianpur.

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[1] A. Budhiraja and G. Kallianpur, Hilbert space valued traces and multiple Stratonovich integrals with statistical applications, UNC Center for Stochastic Processes Technical Report No. 408, Nov. 93. To appear in Jerzy Neyman Memorial Issue of *Probab. and Math. Statist.*

[2] A. Budhiraja and G. Kallianpur, Multiple Ogawa integrals, multiple Stratonovich integrals and the generalized Hu–Meyer formula, UNC Center for Stochastic Processes Technical Report No. 442, July 94, to appear in *Appl. Math. Optimization.*

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[4] A. Budhiraja and G. Kallianpur, Two results on multiple Stratonovich integrals, UNC Center for Stochastic Processes Technical Report No. 457, June 95. Submitted to *Statistica Sinica.*

M.V. BURNASHEV

Professor Marat Burnashev, of the Institute for Problems of Information Transmission, Russian Academy of Science in Moscow, visited the Center for the period November and December 1994.

His research during that time is reported in the following technical report.

1. Asymptotic expansions for median estimates of parameter [1]

Asymptotic expansions are obtained for the distribution of the median (of empirical distribution) estimate of a parameter in additive noise with a symmetric density. For a Laplacian (i.e. two-sided exponential) density this estimate coincides with the maximum likelyhood estimate. As a corollary we get asymptotic expansions for moments of these estimates. Numerical comparisons with exact data provided show that the use of asymptotic expansions significantly increases the accuracy of statistical inferences already for relatively small sample sizes.

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RAY CHENG

Professor Ray Cheng of the Department of Mathematics at the University of Louisville visited the Center for two months and worked on the structure of two-parameter random fields which is relevant to the problem of prediction. He completed the following technical reports.

1. Outer factorization of operator valued weight functions on the torus [1]

An exact criterion is derived for an operator-valued weight function $W(e^{is}, e^{it})$ on the torus to have a factorization $W(e^{is}, e^{it}) = \Phi(e^{is}, e^{it})^* \Phi(e^{is}, e^{it})$, where the operator valued Fourier coefficients of Φ vanish outside of the Helson-Lowdenslager halfplane $\Lambda = \{(m,n) \in \mathbf{Z}^2 : m \geq 1\} \cup \{)0,n) : n \geq 0\}$, and Φ is "outer" in a related sense. The criterion is expressed in terms of a regularity condition on the weighted space $L^2(W)$ of vector valued functions on the torus. A logarithmic integrability test is also provided. The factor Φ is explicitly constructed in terms of Toeplitz operators and other structures associated with W. The corresponding version of Szegö's infimum is given.

2. Operator valued functions of several variables: Factorization and invariant subspaces [2]

This work is an attempt to extend the classical function theory on the Hardy space H^2 to certain classes of operator valued functions of several variables. Of course, it is impossible to carry over all of the interesting details. Our focus is to adapt the notions of inner and outer functions, so as to preserve two basic factorization theorems. We also establish a sort of Beurling-Lax theorem to describe a class of associated invariant subspaces. The overall approach concerns functions on the torus, which generally cannot be realized as the boundary limits of analytic functions in the complex sense. Accordingly, our techniques are chiefly borrowed from multiple Fourier series and shift analysis.

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[2] R. Cheng, Operator valued functions of several variables: Factorization and invariant subspaces, UNC Center for Stochastic Processes Technical Report No. 379, Nov. 92.

DARYL DALEY

Dr. Daryl Daley (of the Australian National University) conducted research on the strong law of large numbers for dependent sequences, during a short visit to the Center in April 1993. This work, joint with R. Foley and T. Rolski, is reported as [1] below and summarized as follows.

1. A note on convergence rates in the strong law for strongly mixing sequences [1]

For partial sums $\{S_n\}$ of a stationary ergodic sequence $\{X_n\}$ with zero mean we find conditions for $\sum_{n=1}^{\infty} n^{\gamma-1} \Pr\{\sup_{k\geq n}(S_k/k) > \epsilon\} < \infty$ in terms of the strong mixing coefficients $\{\alpha_n\}$ and moments of certain functions of the marginal incremental variable X_1.

References

[1] Daley, D.J., Foley, R. and Rolski, T., A note on convergence rates in the strong law for strongly mixing sequences, UNC Center for Stochastic Processes TEch-nical Report No. 395, June 93.

ISSA FAKHRE-ZAKERI

Professor Issa Fakhre-Zakeri of the Department of Mathematics of the University of Maryland visited the Center during the fall of 1992. He worked on inference problems for stationary linear time series with heavy tails jointly with S. Cambanis. He also visited the Center during August 1994 - June 1995.

1. (with S. Cambanis) The prediction of heavy-tailed autoregressive sequences: Forward versus reversed time. [1]

This work was reported under Cambanis.

2. (with J. Farshidi) A central limit theorem with random indices for stationary linear processes. [2]

This work was reported under Farshidi.

3. (with J. Farshidi) Limit theorems for sample covariances of stationary linear processes with applications to sequential estimation. [3]

This work was reported under Farshidi.

References

[1] S. Cambanis and I. Fakhre-Zakeri, The prediction of heavy-tailed autoregressive sequences: Forward versus reverse time. UNC Center for Stochastic Processes Technical Report No. 383, Revised in Nov. 1993. *Theor. Probab. Appl.*, 1994, to appear.

[2] I. Fakhre-Zakeri and J. Farshidi, A central limit theorem with random indices for stationary linear processes, UNC Center for Stochastic Processes Technical Report No. 363, Apr. 92.

[3] I. Fakhre-Zakeri and J. Farshidi, Limit theorems for sample covariances of stationary linear processes with applications to sequential estimation, UNC Center for Stochastic Processes Technical Report No. 380, Sept. 92.

JAMSHID FARSHIDI

Dr. Jamshid Farshidi from the Department of Probability and Statistics of Michigan State University spent the academic year September 1992 through August 1993 as a postoctoral visitor to the center. He visited again in March and April 1995. He worked on the problem of prediction of stationary time series [1] and of random fields (see Kallianpur's section) and on inference for stationary linear time series (jointly with I. Fakhre-Zakeri) [3,4]. He has also begun working on heavy tailed stationary time series and more specifically on the prediction of harmonizable stationary stable processes.

1. Autoregressive expansion of the linear predictor for stationary stochastic processes [1]

The principal problems considered are the existence and uniqueness of an autoregressive expansion of the linear predictor for a discrete stationary process with spectral density f and optimal factor φ, and the invertibility of the process X. The main results are:

(1) the equivalence of the strong convergence of an autoregressive series to the linear predictor, with its boundedness, and with its weak convergence;

(2) the uniqueness of an autoregressive expansion;

(3) the equivalence of an autoregressive expansion with the invertibility of the process;

(4) the sufficiency of the condition $(1/f) \in L^1$ for the existence, convergence, uniqueness of the autoregressive expansion and the invertibility of the process;

(5) a necessary condition based on φ and f for the existence, uniqueness, and convergence of an autoregressive expansion, and invertiblity of the process.

(with G. Kallianpur and V. Mandrekar) Spectral characterization and autoregressive expansion of linear predictors for second order stationary random fields (SOSRF), Part I

Listed under G. Kallianpur's work.

3. (with I. Fakhre-Zakeri) A central limit theorem with random indices for stationary linear processes [3]

A central limit theorem with random indices is obtained for stationary linear process $X_t - \mu = \sum_{j=0}^{\infty} a_j \eta_{t-j}$, where $\{\eta_t\}$ are independent and identically distributed random variables with mean zero and finite variance and $\sum_{j=0}^{\infty} |a_j| < \infty$.

4. (with I. Fakhre-Zakeri) Limit theorems for sample covariances of stationary linear processes with applications to sequential estimation [4]

The strong consistency and rate of convergence are established under optimal conditions for the asymptotic variance of the sample mean of a stationary linear process. Applications are made to the problem of sequential point and fixed width confidence interval estimation of the mean of a stationary linear process.

References

[1] J. Farshidi, Autoregressive expansion of the linear predictor for stationary stochastic processes, UNC Center for Stochastic Processes Technical Report No. 360, March 92.

[2] J. Farshidi, G. Kallianpur and V. Mandrekar, Spectral characterization and autoregressive expansion of linear predictors for second order stationary random fields (SOSRF), Part I: Half planes, UNC Center for Stochastic Processes Technical Report No. 381, Dec. 92.

[3] I. Fakhre-Zakeri and J. Farshidi, A central limit theorem with random indices for stationary linear processes, UNC Center for Stochastic Processes Technical Report No. 363, April 92.

[4] I. Fakhre-Zakeri and J. Farshidi, Limit theorems for sample covariances of stationary linear processes with applications to sequential estimation, UNC Center for Stochastic Processes Technical Report No. 380, September 92.

STERGIOS B. FOTOPOULOS

Professor Stergios Fotopoulos of the Department of Management and Systems in the College of Business and Economics of Washington State University spent a sabbatical year at UNC-CH during 1992-93 and visited the Center for five months. He worked on the strong approximation of quantile processes of stationary mixing sequences, and on the form of the conditional variance for stable random vectors jointly with S. Cambanis.

1. Strong approximation of the quantile process and its applications. [1]

We consider strictly stationary, strongly mixing random sequences. The large sample strong approximation properties of their empirical process have been studied in the literature when the strong mixing coefficient decreases at polynomial order. This work has two main objectives. First it establishes strong approximation results for the quantile process when the strong mixing coefficient decays at polynomial rate, i.e. it shows that the sequence of quantile processes behaves like a sequence of Brownian bridges. Secondly, the first result is used to construct simultaneous confidence intervals for the unknown quantile function and to obtain one-step-ahead prediction intervals for future observations. The results are obtained by relating the empirical and the quantile processes.

2. Multiple conditional variance on stable vectors. [2]

A remarkable property of jointly Gaussian random variables is that conditional variances are nonrandom (i.e. degenerate). For bivariate symmetric stable r.v.'s (that are not Gaussian) this is no longer the case; Wu and Cambanis (1991) derived necessary and sufficient conditions for the conditional variance to be finite, and showed that it has a universal functional form, independent of the joint distribution, and that the variance increases (unboundedly) with the increasing absolute value of the given r.v. In [4] we consider the conditional variance of one r.v. given n other r.v.'s, when they are jointly symmetric stable (and not Gaussian). Necessary and sufficient conditions are derived for the conditional variance to be finite, and its expression is obtained. When the n given r.v.'s are independent, the conditional variance is a sum of n universal functions each depending on one of the conditioned r.v.'s; these are multiples of the bivariate conditional universal variance function, but the coefficients not those appearing in the expression of the bivariate conditional variance, of which at most one may be finite! We also apply these results to certain stable processes, such as scale mixtures of Gaussian processes and harmonizable processes.

References

[1] S.B. Fotopoulos, S.K. Ahn, and S. Cho, Strong approximation of the quantile process and its applications, Institute of Statistics Mimeo Series No. 2091, Jan. 93.

[2] S. Cambanis and S. Fotopoulos, Conditional variance for stable random vectors, UNC Center for Stochastic Processes Technical Report No. 410, Dec. 93.

BRONIUS GRIGELIONIS

Bronius Grigelionis of the Institute of Mathematics and Informatics, Lithuanian Academy of Sciences in Vilnius visited the Center during October 1993 and again during the Bernoulli Conference in June 1994. His research is reported below:

1. Conditionally exponential families and Lundberg exponents of Markov additive processes [1]

Martingale characterization and the Doob–Esscher transforms of Markov additive processes are given. These results are applied for evaluation of Lundberg exponents of one dimensional projection of the additive component.

References

[1] B. Grigelionis, Conditionally exponential families and Lundberg exponents of Markov additive processes, UNC Center for Stochastic Processes Technical Report No. 420, Jan. 94. *Prob. Theory and Math. Statistics*, B. Grigelionis, et al, eds., 1994, VSP/TEV, 337-350.

CHRISTIAN HOUDRÉ

Dr. Christian Houdré of the Department of Mathematics of the University of Maryland, was at the Department of Statistics of Stanford University, and now at Georgia Tech University, visited the Center for two months during May and June 1992 and one week in April 1993. He worked primarily on the ramification of wavelets in stochastic processes [1,2,3], the latter being ongoing collaboration with S. Cambanis. He also worked on stable stochastic processes jointly with M. Hernández [4] and on variance inequalities for functions of Gaussian random variables jointly with A. Kagan [5].

1. Wavelets, probability and staitstics: Some bridges [1]

The rôle of some wavelet methods in probability and statistics is illustrated via a sample of three problems: We show how properties of processes can be read off properties of their wavelet transform. We discuss how the missing data problem can be approached via frames of complex exponentials. We explain how wavelets can be used to span classes of admissible estimators in non-parametric function estimation. It is also the purpose of this paper to show that bridges can be crossed in the other direction. Random products of matrices determine the smoothness of compactly supported wavelets. Non stationary prediction theory gives new results on frames in Hilbert space.

2. Path reconstruction of processes from missing and irregular samples [2]

A criterion is provided for the reconstruction of the paths of non-stationary band-limited processes using irregulary spaced samples by means of an interpolation formula. Its rate of convergence is studied along with its truncation error. These results provide irregular sampling theorems for, say, deterministic signals corrupted by additive noise, and a potential solution to the missing data problem: interpolation from sparse or missing data can be achieved under a density condition. The analysis involves classical results on non-harmonic Fourier series as well as more recent results on frames and wavelets.

3. Wavelet transforms of random processes [3]

This was included under Stamatis Cambanis's section.

4. Disjointness results for some classes of stable processes [4]

The disjointness of two classes of stable stochastic processes: moving averages and Fourier transforms is discussed. Results on the incompatibility of these two representations date back to Urbanik (1964). Here we extend various earlier disjointness results to encompass larger classes of processes, allowing e.g. the noise of a moving average process to be nonstationary and showing that all moving average processes are Fourier transforms in the summability sense.

5. Variance inequalities for functions of Gaussian variables [5]

When X is a standard Gaussian random variable and G an absolutely continuous function, the equality $Var[G(X)] \leq E[G'(X)]^2$ was proved in Nash (1958) and later rediscovered in Brascamp and Lieb (1976) as a special case of a general inequality in Chernoff (1981). All the proofs are based on properties of the Gaussian density. By using the characteristic function rather than the density, generalizations with higher order derivatives are obtained. The method also establishes potentially useful connections with karlin's total positivity.

References

[1] C. Houdré, Wavelets, probability and statistics: Some bridges, UNC Center for Stochastic Processes Technical Report No. 376, October 1992

[2] C. Houdré, Path reconstruction of processes from missing and irregular samples, UNC Center for Stochastic Processes Technical Report No. 359, Feb. 92. *Ann. Probability*, to appear.

[3] S. Cambanis and C. Houdré, Wavelet transform of random processes, in preparation.

[4] M. Hernandez and C. Houdré, Disjointness results for some classes of stable processes, UNC Center for Stochastic Processes Technical Report No. 375, October 1992. *Studia Mathematica* 105 (3), 1993, 237–252.

[5] C. Houdré and A. Kagan, Variance inequalities for functions of Gaussian variables, UNC Center for Stochastic Processes Technical Report No. 374, October 1992.

HARRY L. HURD

Dr. Harry Hurd was a part-time visitor to the Center throughout the year and continued the systematic study of non-stationary processes which are periodically correlated jointly with D. Dehay (Univ. of Rennes, France), Dr. C. Jones (H.L. Hurd Associates) and G. Kallianpur.

1. Spectral theory for periodically and almost periodically correlated random processes: A survey. [1]

This paper contains a survey of the spectral theory of periodically correlated and almost periodically correlated stochastic processes. These processes are also called cyclostationary and almost cyclostationary, and we give some remarks concerning the historical development of the two nomenclatures. In addition to the survey on periodically and almost periodically correlated processes, some topics for future research are given.

The theory of periodically and almost periodically correlated processes, which began with Gladyshev (1961,1963), is substantially based upon the theory of weakly stationary processes. There is a spectral theory of the correlation that uses Fourier series and Fourier transforms of complex measures along with the fact that the correlation must be non-negative definite. As in the case of stationary processes, the Fourier coefficients (which are functions of a lag variable) of the correlation function and their corresponding "spectral" densities may be consistently estimated from single sample paths.

Periodically correlated processes have a natural unitary operator that is essential to the fact that second order periodically correlated sequences of period T are exactly the same (there is a bijection) as T-dimensional stationary vector sequences and that continuous-time periodically correlated processes may be viewed as infinite dimensional stationary sequences. The unitary operator is shown to play a key role in representations of periodically correlated processes. Although there does not appear to be a natural unitary operator (or even a group of unitary operators) associated with every almost periodically correlated process, there is a large subclass for which groups of unitary operators are present.

2. Dynamical systems with cyclostationary orbits. [2]

In an attempt to better understand physical mechanisms that generate cyclostationary (periodically correlated) processes we have examined orbits generated by peridocially perturbing a parameter of a dynamical system. A physical example is the effect of the rotation of the earth on meteorological processes. Using statistical tests for the presence of cyclostationarity, we show that orbits of the periodically perturbed logistic map are consistent with the presence of cyclostationarity. Further, the orbit of an unperturbed system also indicates the presence of cyclostationarity. In constrast to the power spectrum, the spectral correlation methods used for determining the presence of cyclostationarity utilize both amplitude and phase of the sample Fourier transform.

(with G. Kallianpur) Periodically Correlation (PC) Processes and Random Fields

This work was reported under Kallianpur's section.

References

[1] D. Dehay and H.L. Hurd, Spectral theory for periodically and almost periodically correlated random processes: A survey, UNC Center for Stochastic Processes Technical Report No. 412, Dec. 93. *Cyclostationarity in Communications and Signal Processing*, W.A. Gardner, Ed., IEEE Press, 1993, to appear.

[2] H.L. Hurd and C. Jones, Dynamical systems with cyclostationary orbits, UNC Center for Stochastic Processes Technical Report No. 413, Dec. 93.

[3] H. Hurd and G. Kallianpur, Periodically correlated processes and their relationship to $L_2[0,T]$-valued stationary sequences, UNC Center for Stochastic Processes Technical Report No. 358, *Nonstationary stochastic processes and their applications*, A.G. Miamee ed., World Scientific, 1992, 256-287.

KAZUYUKI INOUE

Professor Kazuyuki Inoue of the Department of Mathematics, Faculty of Science, Shinshu University, was a sabbatical visitor at the Center for Stochastic Processes for a seven month period. Inoue's current interests are in problems of equivalence and singularity of processes with independent increments and of more general infinitely divisible processes. Research carried out during his stay at the Center is described below.

1. Admissible perturbations of processes with independent increments. [1]

The paper investigates conditions on the law equivalence of $\mathbf{R}^d$-valued stochastically continuous processes with independent increments and with no Gaussian component. This problem is studied from the standpoint of perturbations. Given two mutually independent processes $\mathbf{X} = \{X(t)\}$ and $\hat{\mathbf{X}} = \{\hat{X}(t)\}$, we put $\mathbf{X}' = \{X'(t) = X(t) + \hat{X}(T)\}$. Then $\mathbf{X}'$ is called an admissible perturbation of $\mathbf{X}$, if $\mathbf{X}$ and $\mathbf{X}'$ induce equivalent probability measures on the space of sample functions. The class of admissible perturbations of $\mathbf{X}$ is described in terms of the time-jump measures M and $\hat{M}$ associated with $\mathbf{X}$ and $\hat{\mathbf{X}}$ respectively. The fine structure of this class is obtained for processes related to special infinitely divisible distributions such as stable distributions, distributions of class L and their mixtures. A simplified proof is given of the theorem of Skorokhod on the law equivalence of $\mathbf{R}^d$-valued processes with independent increments.

2. A constructive approach to the law equivalence of infinitely divisible random measures. [2]

We establish a sufficient condition for the law equivalence of infinitely divisible random measures on a measurable space $\mathbf{T}$ equipped with a δ-ring. Given a σ-finite measure M on the product space $\mathbf{S} = \mathbf{T} \times (\mathbf{R}\backslash\{0\})$, we construct a Poisson random measure on $\mathbf{S}$ with intensity M and a class of infinitely divisible random measures on $\mathbf{T}$. These random measures are defiend on some infinite product probability space connected with a measure space $(\mathbf{S}, S, M)$. Our main theorem is proved based on this method with Kakutani's theorem on the equivalence of infinite product probability measures. We also obtain a class of infinitely divisible random measures on $\mathbf{T}$ which are realized by real valued signed measures on T.

References

[1] K. Inoue, Admissible perturbations of processes with independent increments, UNC Center for Stochastic Processes Technical Report No. 397, June 93.

[2] K. Inoue, A constructive approach to the law equivalence of infinitely divisible random measures, UNC Center for Stochastic Processes Technical Report No. 409, November 93.

GERALD W. JOHNSON

Professor Gerald W. Johnson of the University of Nebraska, Lincoln spent the periods June 1993 and September 1994 through January 1995 at the Center to continue collaboration with G. Kallianpur. In continuation of their earlier work on Hilbert space valued traces they obtained easily verifiable sufficient conditions for the existence of traces in the paper listed below.

In collaboration with Kallianpur, research work was also started on operator-valued multiple stochastic integrals. This work is reported under G. Kallianpur's section.

References

[1] G.W. Johnson and G. Kallianpur, Remarks on the existence of k-traces, UNC Center for Stochastic Processes Technical Report No. 404, Aug. 93. *Chaos Expansions, Multiple Wiener Itô Integrals and their Applications*, C. Houdré and V. Perez-Abreu, eds., CRC Press, 47-72.

ANU KANNIGANTI

Dr. Anu Kanniganti from the Statistics Department of Purdue University spent a postdoctoral year September 1992 - August 1993 at UNC-CH. She pursued her dissertation work on the frontier of a branching Brownian motion with killing.

Branching Brownian motion with killing. [2]

The rate of growth of the frontier of branching Brownian motion has been studied in a series of papers. Under certain assumptions on the branching rate, the frontier grows linearly, and the limiting distribution is a "travelling wave" - i.e. the frontier modulo its median converges to a non-degenerate random variable (McKean, 1978; Lalley and Sellke, 1988, 1990). In [1] we found that if the particles are in addition subject to killing, with a killing function which increases without bound away from the origin, then the results are qualitatively different - the growth is now sublinear; for the specific form $k(x) = |x|^a, a > 0$, we obtained the explicit growth rate, and found that the limiting distribution is a "degenerate" wave.

The present study consists of finding limiting results of the above type for more general branching diffusions, and for a wider class of killing functions. These results essentially repose on a large deviation type theorem for killed diffusions. It is interesting that for killed Brownian motion, for the special class of killing functions described above, it is a direct consequence of earlier results for ultracontractive semigroups (Simon and Davies, 1989). However, our methods apply to a larger class of killing functions than those of Simon and Davies.

References

[1] A. Kanniganti and S. Lalley, The frontier of a branching Brownian motion with killing, Technical Report, Department of Statistics, Purdue University, West Lafayette, IN, 1992.

[2] A. Kanniganti, Branching Brownian motion with killing, in preparation.

R.L. KARANDIKAR

Professor Karandikar of the Indian Statistical Institute, Delhi, visited the Center for four months (April - July) 1992. In addition to the completion of work done jointly with A. Bhatt, G. Kallianpur and J. Xiong [1], he collaborated with V.G. Kulkarni of the Operations Research department on the study of a second-order fluid flow model [2] and with G. Kallianpur on nonlinear transformations of abstract Wiener measure [3]. His work on nonlinear filtering theory was done in collaboration with A. Bhatt and G. Kallianpur [4]. He also visited the Center in June 1994.

On interacting systems of Hilbert space valued diffusions [1]

Listed under Kallianpur's section.

2. Second-order fluid flow model of a data-buffer in random environment [2]

This paper considers a stochastic model of a data-buffer in a telecommunication network. Let $X(t)$ be a buffer-content at time t. The $\{X(t), t \geq 0\}$ process depends on a finite state continuous time Markov process $\{Z(t), t \geq 0\}$ as follows: during the time-intervals when $Z(t)$ is in state i, $X(t)$ is a Brownian motion with drift μ_i, variance parameter σ_i^2 and a reflecting boundary at zero. This paper studies the steady state analysis of the bivariate process $\{(X(t), Z(t)), t \geq 0\}$ in terms of the eigenvalues and eigenvectors of a non-linear matrix system. Algorithms are developed to compute the steady state distributons as well as moments.

Numerical work is reported to show that the variance parameter has a dramatic effect on the buffer content process. Thus buffer sizing done with first order fluid flow models (with zero variance parameters) should be used with care.

3. Nonlinear transformations of the canonical Gauss measure on Hilbert space and absolute continuity [3]

Listed under Kallianpur's work.

4. (with Bhatt and Kallianpur) Uniqueness and robustness of solution of measure valued equations of nonlinear filtering [4]

References

[1] A.G. Bhatt, G. Kallianpur, R.L. Karandikar and J. Xiong, On interacting systems of Hilbert space valued diffusions, *Appl. Math. Optimization*, to appear.

[2] R.L. Karandikar and V.G. Kulkarni, Second-order fluid flow model of a data-buffer in random environment, *J. Appl. Probab.*, **1**, No. 1, 77-88.

[3] G. Kallianpur and R.L. Karandikar, Nonlinear transformations of the canonical Gauss measure on Hilbert space and absolute continuity, *Acta. Appl. Math.*, **35**, 1994, 63-102.

[4] A.G. Bhatt, G. Kallianpur and R.L. Karandikar, Uniqueness and robustness of solution of measure valued equations of nonlinear filtering, *Annals Probab.*, to appear.

YURI KIFER

Professor Yuri Kifer of the Hebrew University, Jerusalem, visited the Center and the Department of Mathematics for four months in the fall of 1992. He gave a series of seminars in the center and lectures in the Mathematics Department on large deviations which are now published in [1]. He also worked on large deviation problems in statistical mechanics [2].

Large deviations for $\mathbf{Z}^d$-actions. [1]

The results of Föllmer and Orey (1988) on large deviations in the statistical mechanics setup are generalized to the case of subshifts of finite type where not all configurations are permissible. This includes the hard core models, where for instance in the two dimensional lattice at each site a particle can have spin plus or minus but two pluses cannot be in neighboring sites. The generalization requires the development of a new technique.

References

[1] Y. Kifer, Topics on Large Deviations and Random Perturbations, Carolina Lecture Series, Department of Mathematics, University of North Carolina at Chapel Hill, 1993.

[2] A. Eizenberg, Y. Kifer and B. Weiss, Large deviations for $\mathbf{Z}^d$-actions, 1992, manuscript submitted for publication.

MARIE KRATZ

In several visits to the Center during December 1994 and during January and February 1992, Dr. M. Kratz (of Université René Descartes, Paris V) studied convergence rates for extremes of stationary normal processes. The results of this research (done jointly with H. Rootzén) are reported in [1] and summarized as follows:

1. (with Rootzén) On the rate of convergence for extremes of square differentiable stationary normal processes [1]

Let $\xi(x) : t \geq 0$ be a normalized continuous mean square differentiable stationary normal process with covariance function $r(t)$. Further, let

$$\rho(t) = \frac{(1 - r(t))^2}{1 - r(t)^2 + r'(t)|r'(t)|}$$

and set

$$\delta = \frac{1}{2} \wedge \inf_{t \geq 0} \rho(t).$$

The bounds are roughly of the order $T^{-\delta}$ for the rate of convergence of the distribution of the maximum and of the number of upcrossings of a high level by $\xi(t)$ in the interval $[0, T]$. The results assume that $r(t)$ and $r'(t)$ decay polynomially at infinity and that $r''(t)$ is suitably bounded. For the number of upcrossings it is in addition assumed that $r(t)$ is non-negative.

References

[1] M. Kratz and H. Rootzén, On the rate of convergence for extremes of square differentiable stationary normal processes, UNC Center for Stochastic Processes Technical Report No. 439, July 94.

RAOUL LePAGE

Professor Raoul LePage of Michigan State University visited the Center during April and May 1994. His work was concerned with three separate topics:

1. Stable laws
2. Option pricing and
3. Inverse problems.

1. (with K. Podgorski and M. Ryznar) Strong and conditional invariance principles for samples attracted to stable laws [1]

The authors prove almost sure convergence of a representation of normalized partial sum processes of a sequence of i.i.d. random variables from the domain of attraction of an α–stable law, $\alpha < 2$. They obtain an explicit form of the limit in terms of the LePage series representation of stable laws. One consequence of these results is a conditional invariance principle having applications to resampling by signs and permutations as well as to option pricing.

2. A representation theorem for linear functions of random variables with applications to option pricing [2]

The basic idea: the price $\lambda(X)$ of a random variable X is the point beyond which a maximizer of the expectation fo the logarithm will move a portion of their portfolio X^* onto X. This price is computed and found to be $\lambda(X) = E\frac{X}{X^*}$. The calculation is illustrated for contingent claims in a one dimensional setting where it gives the Black–Scholes price, but is very generally applicable since it rests upon a representation theorem for linear functions of random variables and prices must in any case be linear to avoid arbitrage.

3. (with K. Podgorski) A nonlinear solution of inverse problems [3]

The authors consider a classical problem of estimating or approximating a density given the information consisting of the values of some of its integrals. The method will have direct applications in many problems of density, spectral density and image analysis which will not be treated in any detail here. One widely used method chooses the density which minimizes a cross entropy functional. They propose a different method based on maximizing a functional. However as an estimate we take *the reciprocal of the maximizing random variable* multiplied by a density. In general, restorations obtained utilizing this new method differ from those obtained by entropy methods. Their properties as well as some examples demonstrate the competitiveness of the proposed method.

References

[1] R. LePage, K. Podgorski and M. Ryznar, Strong and conditional invariance principles for samples attracted to stable laws, UNC Center for Stochastic Processes TechnicalReport No. 425, Mar. 94.

[2] R. LePage, A representation theorem for linear functions of random variables with applications to option pricing, UNC Center for Stochastic Processes Technical Report No. 427, Mar. 94.

[3] R. LePage and K. Podgorski, A nonlinear solution of inverse problems, UNC Center for Stochastic Processes TechnicalReport No. 435, June 94.

GEORG LINDGREN

Dr. Georg Lindgren (of Lund University) spent a month during June 1994 in Chapel Hill and August 1994 in Sweden as a visitor/consultant working on the reliability of ocean structures. He worked with Rychlik on obtaining confidence sets for contours of a Gaussian surface, reported in [2] and summarized as follows.

1. (with Rychlik, I. and Lin, Y.K.) Markov based correlations of damage cycles in Gaussian and non–Gaussian loads [1]

This work with Rychlik and Lin is described in the listing for Rychlik.

2. (with Rychlik, I.) Confidence sets for level contours [2]

The paper presents a method for adding confidence limits to level curves, drawn on a map of a Gaussian random surface, measured with or without error on a regular or irregular grid. The method is based on the conditional level crossing intensity measure for non–stationary Gaussian fields.

References

[1] Rychlik, I., Lindgren, G. and Lin, Y.K., Markov based correlations of damage cycles in Gaussian and non–Gaussian loads, UNC Center for Stochastic Processes Technical Report No. 416, Dec. 93.

[2] Lindgren, G. and Rychlik, I., Confidence sets for level contours, UNC Center for Stochastic Processes Technical Report No. 441, July 94.

J.-C. MASSÉ

Professor Jean-Claude Massé of the Department of Mathematics and Statistics of the University of Laval visited the Center for six weeks during mid October - November 1991 and studied, jointly with C.A. León, the properties of the simplicial median of Oja with a view towards the study of medians of random processes.

1. (with C.A. León) La médiane simpliciale d'Oja: existence, unicité et stabilité [1]

Oja (1983) examined various ways of measuring location, scatter, skewness and kurtosis for multivariate distributions. Among other measures of location, he introduced a generalised median, the Oja median. The authors study three fundamental theoretical properties of that median: existence, uniqueness and consistency.

Massé's work is included here because his technical report was concluded in March 1992.

References

[1] C.A. León and J-C Massé, La médiane simpliciale d'Oja: existence, unicité et stabilité, UNC Center for Stochastic Processes Technical Report No. 362, March 92.

PAUL McGILL

Professor Paul McGill of the Dublin Institute of Advanced Studies, visited the Center during January - August 1994 and June - August 1995.

1. Brownian motion, matrix factors, and excursions [1]

The H^+/H^- factoring of matrix functions of a complex variable is a well-known and difficult problem in analysis. There is an existence theorem [2] but no general algorithm. Such results find application in control, stability of nonlinear equations, and solution of Wiener-Hopf problems. See [3] for an account of the 2×2 case and how to determine the factor entries up to multiples of entire functions.

2. First exit of a Lévy process from an interval [4]

We illustrate the probabilistic approach to Wiener-Hopf equations by a simple example: finding the first exit jump of a Lévy process from an interval. The method is not so well-known, in part because for real processes there are more transparent arguments. But in higher dimensions [1] one needs to be systematic. The ideas used here come from analysis [2] and are connected with problems of matrix factorisation.

3. Path properties in supercritical branching [5]

This technical report is in preparation.

4. Upper functions, large deviations, and random pursuit. [6]

This technical report is in preparation.

5. Fluctuating time changes for real diffusions. [7]

This technical report is in preparation. **6. A plug for WH methods.** [8]

This technical report is in preparation.

References

[1] P. McGill, Brownian motion, matrix factors, and excursions, UNC Center for Stochastic Processes Technical Report No. 401, Aug. 93.

[2] N.I. Mushkelishvili, *Singular integral equations*, Noordhoff, Groningen 1953.

[3] D.S. Jones, Wiener-Hopf splitting of a 2×2 matrix. *Proc. Roy. Soc. Lond. A.* **434** (1991) 419-433.

[4] P. McGill, First exit of a Lévy process from an interval, UNC Center for Stochastic Processes Technical Report, in preparation.

[5] P. McGill, Path properties in supercritical branching, UNC Center for Stochastic Processes Technical Report, in preparation.

[6] P. McGill, Upper functions, large deviations, and random pursuit, UNC Center for Stochastic Processes Technical Report, in preparation.

[7] P. McGill, Fluctuating time changes for real diffusions, UNC Center for Stochastic Processes Technical Report, in preparation.

[8] P. McGill, A plug for WH methods, UNC Center for Stochastic Processes Technical Report, in preparation.

TOMMY NORBERG

Dr. Tommy Norberg of Chalmers University, Göteborg, continued work begun in a visit just prior to the present reporting period, on the theory of random sets.

1. A note on continuous collections of sets [1]

The paper provides conditions under which a given family $\mathcal{H}$ of sets is continuous with its Lawson dual $\hat{\mathcal{H}}$ isomorphic to another collection $\mathcal{T}$ of sets.

References

[1] T. Norberg, A note on continuous collections of sets, UNC Center for Stochastic Processes Technical Report No. 428, Mar. 94.

OLGA OLEINIK

Professor Olga Oleinik of Moscow State University spent April 1994 at the Center. In addition to giving seminars, her work at the Center was concerned with the interconnection between analytical and probabilistic methods in homogenization problems.

1. Averaging and some problems of probability [1]

In this paper it is shown how analytical methods can solve probabilistic problems connected with homogenization.

Homogenization (averaging) is a new branch of the theory of partial differential equations with many applications to mathematical physics, chemistry, biology and engineering. It is important for applications to study so called composite materials, i.e. materials consisting of very small pieces of different kinds of materials. If a composite material has a random structure we have the probabilistic problems of finding effective characteristics of physical processes which occur in this material.

References

[1] O. Oleinik, Averaging and some problems of probability, UNC Center for Stochastic Processes Technical Report No. 455, April 95.

VASSILIS PAPANICOLAOU

Professor Papanicolaou of the Department of Mathematics of Duke University [and now at the Department of Mathematics of Wichita State University] was at the Center for two months in the summer of 1992. His interest in Feynman integrals led to the study of some problems of integration over Hilbert space and extensions involving multiparameter Gaussian processes of previous work by G. Kallianpur, D. Kannan and R.L. Karandikar (Analytic and sequential Feynman integrals on abstract Wiener and Hilbert spaces, and a Cameron-Martin formula, *Ann. Inst. H. Poincare*, **21**, 1985, 323-361).

1. Integration over Hilbert spaces: Examples inspired by the harmonic oscillator [1]

The research produced some examples of functional integrals over Hilbert spaces where the integrand is analogous to the one for the quantum mechanical harmonic oscillator. In one case the continuum limit of a sequence of coupled harmonic oscillators is considered.

References

[1] G. Kallianpur and V.G. Papanicolaou, Integration over Hilbert spaces: examples inspired by the harmonic oscillator, UNC Center for Stochastic Processes Technical Report No. 367, July 92.

MIREK PAWLAK

Professor Mirek Pawlak of the Department of Electrical and Computer Engineering of the University of Manitoba visited the Center for three months from May through July 1993 and worked on the problem of recovering a deterministic band-limited signal from (independent) noisy samples.

On Recovering Band-Limited Functions from Noisy Samples [1]

The problem of recovering a function of the band-limited class is studied. Estimates derived from a modified version of the cardinal expansion are introduced and their statistical properties are established. This includes the consistency and rate of convergence in the mean square error sense, as well as the asymptotic normality.

References

[1] M. Pawlak, Nonparametric estimation of band-limited functions from noisy samples, UNC Center for Stochastic Processes Technical Report No. 410, Dec. 93.

ROGER PETTERSSON

In two periods as a visitor (during July 1993 and May 1 - June 15, 1994) Dr. Roger Pettersson studied aspects of stochastic differential equations with special reference to the problems associated with reliability of ocean structures. These are reported in [1] and [2] below. The work [1] involved stochastic differential equations with reflecting convex boundaries, the content being summarized as follows:

1. Approximations for stochastic differential equations with reflecting convex boundaries [1]

For a stochastic differential equation

$$d\xi = b(\xi)dt + \sigma(\xi)dB + d\varphi$$

reflecting on the boundary of a closed convex set G we suggest the numerical solution

$$\xi^\delta(t) := \Pi_G\{\xi^\delta(t_{k-1}) + b(\xi^\delta(t_{k-1}))\Delta t_k \cdots, \Delta t_k = t_k - t_{k-1} \leq \delta$$

for $t \in \{t_k, t_{k+1})$ where $0 = t_0 < t_1 < \cdots, \Delta t_k = t_k - t_{k-1} \leq \Delta, \Delta B(t_k) = B(t_k) - B(t_{k-1})$ and $\Pi_{(\cdot)}$ denotes the projection on G.

We prove boundedness of ξ^δ and under suitable conditions, mean square convergence, uniformly on compacts, of ξ^δ to ξ. An application is given for stochastic differential equations with hysteretic components.

2. Yosida approximations for multivalued stochastic differential equations [2]

Convergence of solutions to the stochastic differential equations $d\xi_\lambda(t) = b(t, \xi_\lambda(t)dt - A_\lambda\xi_\lambda(t)dt + \sigma(t, \xi_\lambda(t))dB(t)$ as $\lambda \downarrow 0$, where A_λ is the Yosida approximation of a maximal monotone map A, is proved under suitable integrability conditions. The limit ξ satisfies the multivalued stochastic differential equation $d\xi \in b(t, \xi(t))dt - A\xi(t)dt + \sigma(t, \xi(t))dB(t)$.

Applications are given for stochastic differential equations with discontinuous drift.

References

[1] R. Petersson, Approximations for stochastic differential equations with reflecting convex boundaries, UNC Center for Stochastic Processes Technical Report No. 400, Aug. 93.

[2] R. Pettersson, Yosida appoximations for multivalued stochastic differential equations, UNC Center for Stochastic Processes Technical Report No. 438, July 94. *Stochastics and Stochastic Reports*, **53**, 1995, 107-120.

KRYS PODGORSKI

Professor Krys Podgorski from Michigan State University visited the Center from January - August 1994. During that time he worked on the following technical reports. He is now at Indiana-Purdue University.

1. (with LePage and Ryznar) Strong and conditional invariance principles for sample attracted to stable laws [1]

This is reported under LePage's section.

2. (with R. LePage) A nonlinear solution of inverse problems [2]

This is reported under LePage's section.

3. (with Cambanis and Weron) Chaotic behavior of infinitely divisible processes [3]

This is reported under Cambanis's section.

4. (with G. Simons) On estimation for a binary symmetric channel [4]

The authors consider a binary symmetric channel where the input, modeled as an infinite sequence of bits, is distorted by a Bernoulli noise. in [5] the consistent estimate of the distortion, i.e. of probability that a single bit will be changed, was defined under the assumption that the complexity of the input is finite. The proposed estimation procedure required some prior information about the value of the complexity. In this paper we present an extension of the method which enables consistent estimation of both the distortion and the complexity. Asymptotic properties of estimates are studied.

References

[1] R. LePage, K. Podgorski and M. Ryznar, Strong and conditional invariance principles for sample attracted to stable laws, UNC Center for Stochastic Processes Technical Report No. 425, Mar. 94.

[2] R. LePage and K. Podgorski, A nonlinear solution of inverse problems, UNC Center for Stochastic Processes Technical Report No. 435, June 94.

[3] S. Cambanis, K. Podgorski and A. Weron, Chaotic behavior of infinitely divisible processes, UNC Center for Stochastic Processes Technical Report No. 451, April 95.

[4] G. Simons and K. Podgorski, On estimation for a binary symmetric channel, UNC Center for Stochastic Processes Technical Report No. 461, June 95.

[5] G. Simons, Estimating distortion in a binary symmetric channel consistently, *IEEE Trans. Inform. Theory*, **37**, 1991, 1466-1470.

TOMASZ ROLSKI

Professor Tomasz Rolski of the Mathematical Institute of Wroclaw University in Poland spent the 1992-93 academic year visiting UNC's Department of Operations Research and visited the Center for one month working with D. Daley on the strong law of large numbers for dependent sequences.

1. A note on convergence rates in the strong law for strongly mixing sequences. [1]

This work is described under Daley's work.

References

[1] D.J. Daley, R.D. Foley and T. Rolski, A note on convergence rates in the strong law for strong mixing sequence, UNC Center for Stochastic Processes Technical Report No. 395, June 93.

HOLGER ROOTZÉN

Professor Holger Rootzén (University of Lund, Sweden) spent two weeks in June 1994 as a senior visitor to the Center.

Professor Rootzén's activities were divided into three areas as follows.

1. Tail estimation for stationary sequences [1]

Holger Rootzén and M.R. Leadbetter collaborated in extending work reported previously (as CSP Report 292 with L. de Haan) on the estimation of parameters associated with high values of stochastic sequences. These include the "extremal index", the parameter f a regularly varying tail distribution, tail probabilities and quantiles, under dependence conditions such as strong mixing.

It is planned that this work will be reported in two papers (currently under preparation), divising and extending that in the CSP Report 292.

2. Extremal properties of Markov chains [2]

Professor Rootzén continued work with R. Perfekt on extremal properties of Markov chains, extending that described in the report [2]. The subsequent work is included in the doctoral thesis of R. Perfekt.

3. Related statistical questions

Professor Rootzén conducted related statistical research in

(i) **Quantile estimation in a nonparametric component of variance framework with applications to vision problems** [3]

(ii) **Proportional hazard testing related to strength of materials** [4].

His results under (i) done jointly with Jonny Olsson (who visited the Center in the previous reporting period) are summarized as follows:

Quantile estimators for a non-parametric components of variance situation are proposed and consistency and asymptotic normality is proved. Situations with different numbers of measurement for different subjects are considered. Measurements on separate subjects are assumed independent while measurements on the same subject have a fixed dependence. The estimators are obtained by inverting weighted empirical distribution functions. An "optimal" estimator is derived by choosing weights to minimize the variance of the weighted empirical distribution function. The resulting weights depend on unknown parameters. However, these weights may be estimated from data without affecting asymptotic performance. A simple estimator based on within subject averages is also investigated. Small sample properties are studied by simulation, and as an illustration the estimators are applied to normal limits for differential light sensitivity of the eye.

The work on proportional hazards (joint with A. Deis) provided a k-sample test for proportional hazards and is described in detail as follows:

A test for proportionality of the cumulative hazard functions in $k \geq 2$, possibly censored, samples is proposed. The test does not use dummy time-dependent covariates or partitions of the time axis. It extends a test of Wei (1984) from 2 to k samples, and for $k = 2$ gives an alternative approximation to the test probabilities. It is asymptotically correct and performed well in a small sample simulation sutdy. The test is based on the maximum norm of the score process obtained from Cox' partial likelihood. The test probabilities are obtained by a "parametric bootstrap", i.e. by simulation from the asymptotic distribution, with an unknown variance func-

tion replaced by an estimate. The method is computationally demanding, but still within the capabilities of a standard personal computer. An important advantage s flexibility; by obvious simple changes the program can be used with any test statistic based on the score process. Some problems related to the size effect in the strength of materials are discussed, and the method is applied to a data set on the strengths of carbon fibers. It is also illustrated on two cancer studies considered by Wei.

4. (with M. Kratz) On the rate of convergence for extremes of mean square differentiable stationary normal processes [5]

This work is described under M. Kratz.

References

[1] M.R. Leadbetter and H. Rootzén, Tail estimation for stationary sequences, Revision and extension of UNC Center for Stochastic Processes Technical Report No. 292, in preparaton.

[2] R. Perfekt, Extremal properties of stationary Markov chains with applications, UNC Center for Stochastic Processes Technical Report No. 353, Nov. 1991.

[3] J. Olsson and H. Rootzén, Quantile estimation from repeated measurements, UNC Center for Stochastic Processes Technical Report No. 385, Dec. 1992.

[4] A. Deis and H. Rootzén, A k–sample test for proportional hazards with an application to the strength of materials, UNC Center for Stochastic Processes Technical Report No. 384, Dec. 1992.

[5] M. Kratz and H. Rootzén, On the rate of convergence for extremes of mean square differentiable stationary normal processes, UNC Center for Stochastic Processes Technical Report No. 439, July 1994.

IGOR RYCHLIK

Professor Igor Rychlik (of Lund University, Sweden) visited the Center for two months during June and July 94 to collaborate with M.R. Leadbetter on stochastic problems in the reliability of ocean structures. His work involved a variety of related activities summarized below.

1. (with Michna) Level crossings for stable processes [1]

New techniques for evaluating the mean number of level crossings were developed and applied to stable processes. This is reported in [1] whose summary follows:

An explicit formula is given for the first passage time density for some absolutely continuous process X which can be split $X(t) = G\Delta_1(t) + \Delta_2(t)$, where Δ_1, Δ_2 have absolutely continuous sample paths and the random variable G is independent of processes Δ_1, Δ_2. The result is used to prove Rice's formula for the expected number of crossings of a level in a finite interval for certain absolutely continuous symmetric α–stable processes. Numerical examples illustrate the result.

2. (with Lindgren) Reliability of confidence curves [2]

This work, reported as [2], is described under the listing for its co-author G. Lindgren.

3. (with Johannesson and Leadbetter) Modeling of ocean wave data [3]

The use of functions of Gaussian processes was investigated for the modeling of ocean wave heights. The study centered around data in the U.S. and Europe, for deep water (closely Gaussian) and shallow water (non Gaussian) series. A technical report [3] describing these results is under current preparation.

In related work D.r Rychlik studied the distribution of wave statistics, such as crest–trough amplitudes and crest heights. He showed in particular that conservative results – even for Gaussian processes – were obtained by assuming the widely used narrow band Rayleigh approximations. The study is reported in [4], with the following description:

In this note we give conservative bounds for significant crest height and amplitude obtained from the crossing intensity of a sea. For Gaussian models fo a sea level, we prove that the Rayleigh approximation for the distribution of amplitude and crest height leads to conservative values for the expected significant wave characteristics. The results are illustrated by examples in which we consider both Gaussian and non–Gaussian models for a sea.

4. Cycles and structural fatigue [5]

Dr. Rychlik investigated the properties of so–called "rainflow cycles" which are often used in structural fatigue applications when a highly irregular stress function is involved. This is reported in [5] whose abstract follows:

We discuss some properties of damage functionals defined on a sequence of local extremes in continuous stochastic processes both irregular, e.g. Brownian motion, diffusions, and smooth, e.g stationary Gaussian processes with finite intensity of local maxima. Local extremes are represented as a point process in R^2. The main tools are rainflow cycles and oscillation measures.

In a somewhat different but related line of investigation Dr. Rychlik studied central limit theory for "wave–functionals" of Gaussian processes. Such results are typically very useful particularly when questions of statistical inference arise, since

they can provide the asymptotic distributions needed for estimation and testing. A draft of this work has been completed and it will appear as [6].

5. (with Lindgren and Lin) Markov based correlations of damage cycles in Gaussian and non–Gaussian loads [7]

Dr. Rychlik has (together with G. Lindgren and Y. Lin) also considered Markov modeling for wave cycles with particular application to problems of fatigue. This provides very useful approximation techniques for assessment of stress damage and is described in the following abstract for the report [7]:

The sequence of peaks and troughs in a load process acting on a material, contains important information about the damage caused by the load, e.g. on the growth rate of a widening crack. The stress range, i.e. the difference between a peak and the following trough, is one of the variables that is used to describe e.g. fatigue life under random loading. The moments, in particular the mean and variance, of the load range are important variables that determine the total damage caused by a sequence of stress cycles, and they give the parameters in the distribution of the time to fatigue failure. However, for many random load processes, the successive stress ranges can show considerable correlation, which affects the failure time distribution. In this paper the authors derive the modified failure time distribution under correlated stress ranges, under a realistic approximation that the sequence of peaks and troughs forms a Markov chain. They also present a method to calculate the transition probabilities of the Markov chain for Gaussian load processes with known spectral density. Simulations of Gaussian processes with JONSWAP spectrum, and linear and the Duffing oscillators driven by Gaussian white noise, show very good agreement between observed correlations and those calculated from the Markov approximation. Also the numerically calculated transition probabilities lead to good agreement with simulation.

References

[1] Z. Michna and I. Rychlik, Expected number of level crossings for certain symmetric α–stable processes, UNC Center for Stochastic Processes Technical Report No. 421, Jan. 94.

[2] G. Lindgren and I. Rychlik, How reliable are contour curves? Confidence sets for level contours, UNC Center for Stochastic Processes Technical Report No. 441, July 94.

[3] I. Rychlik, P. Johannesson and M.R. Leadbetter, Statistical analysis of ocean–wave data, UNC Center for Stochastic Processes Technical Report, in preparation.

[4] I. Rychlik, A note on significant wave height, UNC Center for Stochastic Processes Technical Report, in preparation.

[5] I. Rychlik, Extremes, rainflow cycles and damage functionals in continuous random processes, UNC Center for Stochastic Processes Technical Report No. 454, May 95.

[6] V. Piterbarg and I. Rychlik, Central limit theory for wave–functionals of Gaussian processes, UNC Center for Stochastic Processes Technical Report, in preparation.

[7] I. Rychlik, G. Lindgren, Y.K. Lin, Markov based correlations of damage cycles in Gaussian and non-Gaussian loads, UNC Center for Stochastic Processes Technical Report No. 416, Dec. 93.

JACK SILVERSTEIN

Professor Jack Silverstein, from North Carolina State University, visited the Center during September through December 1993. His research work follows.

1. The spectral radii and norms of large dimensional non–central random matrices [1]

Consider a matrix made up of i.i.d. random variables with positive mean and finite fourth moment. Results are given on its spectral norm and (if it is square) spectral radius as the dimension increases.

2. (with S.-I. Choi) Analysis of the limiting spectral distribution of large dimensional random matrices [2]

Results on the analytic behavior of the limiting spectrum distribution of matrices of sample covariance type, studied in Marćenko and Pastur [3] and Yin [4], are derived. Through an equation defining its Stieltjes transform, it is shown that the limiting distribution has a continuous derivative away from zero, the derivative being analytic wherever it is positive, and resembles $\sqrt{|x - x_0|}$ for most cases of x_0 in the boundary of its support. A complete analysis of a way to determine its support, outlined in Marćenko and Pastur [3], is also presented.

References

[1] J.W. Silverstein, The spectral radii and norms of large dimensional non–central random matrices, UNC Center for Stochastic Processes Technical Report No. 405, Oct. 93.

[2] J.W. Silverstein and S.-I. Choi, Analysis of the limiting spectral distribution of large dimensional random matrices, UNC Center for Stochastic Processes Technical Report No. 407, Sept. 93.

[3] V.A. Marcenko and L.A. Pastur, Distribution of eigenvalues for some sets of random matrices, USSR-Sb., 1 (1967), 457-483.

[4] Y.Q. Yin, Limiting spectral distribution for a class of random matrices, *J. Multiv. Analysis*, **20**, 1986, 50-68.

YINGCAI SU

Dr. Yingcai Su, from Arizona State University and a previous graduate student, spent the period July 28 - Aug. 18, 1992 at the Center. During that time, he collaborated with Cambanis on the following.

1. (with S. Cambanis) Asymptotically optimal bivariate quantization using mean square distortion norm [1]

This was reported under Cambanis's work.

2. (with S. Cambanis) Asymptotically optimal bivariate quantization with L_1 distortion norm [2]

This was reported under Cambanis's work.

References

[1] Y. Su and S. Cambanis, Asymptotically optimal bivariate quantization using mean square distortion norm, in preparation.

[2] Y. Su and S. Cambanis, Asymptotically optimal bivariate quantization with L_1 distortion norm, in preparation.

DONATAS SURGAILIS

Dr. Donatas Surgailis of the Institute of Mathematics and Informatics of the Lithuanian Academy of Sciences in Vilnius visited the Center during August 1991 through April 1992. He introduced a new rich class of stationary stable processes generalizing moving averages jointly with S. Cambanis, V. Mandrekar and J. Rosinski.

1. Generalized stable moving averages [1]

In this work the class of non-Gaussian stable moving average processes is extended substantially by the introduction of an appropriate joint randomization of the filter function and of the stable noise, leading to stable generalized moving averages (GMA). The characterization of their distribution through their filter function and their mixing measure leads to a far reaching generalization of a theorem of Kanter (1972).

It is shown that stable GMA's contain sums of independent stable moving averages and that they are still disjoint from the harmonizable processes, but are closed under time invariant filters, and that they are mixing, so they have strong ergodic properties. They lead to a wealth of new examples of self-similar processes, beyond the linear fractional stable motions, and also of processes which are reflection positive, which is a useful weakening of the Markov property.

References

[1] S. Cambanis, V. Mandrekar, J. Rosinski and D. Surgailis, Generalized stable moving averages, UNC Center for Stochastic Processes Technical Report No. 365, April 1992, *Probab. Theory Rel. Fields*, **97**, 1993, 543-558.

CONSTANTIN TUDOR

Constantin Tudor from the Department of Mathematics, University of Bucharest spent January 1994 at the Center. His work, briefly discussed below was in collaboration with G. Kallianpur.

1. (with G. Kallianpur) Almost periodically distributed solutions for diffusion equations in duals of nuclear spaces [1]

The paper discusses the problem of the existence of almost periodic in distribution solutions of nuclear space–valued diffusion equations with almost periodic coefficients. Under a dissipativity condition we prove that the translation of the unique mean square bounded solution is almost periodically distributed. Similar results hold in the affine case under mean square stability of the linear part of the equation if the nuclear space is a component of a spectral compatible family.

References

[1] G. Kallianpur and C. Tudor, Almost periodically distributed solutions for diffusion equations in duals of nuclear spaces, UNC Center for Stochastic Processes Technical Report No. 437, July 94.

C.S. WITHERS

In visits during March - April 1993 and June 1994, Dr. C.S. Withers (of New Zealand Institute of Industrial Research & Development) conducted research in extreme value theory and robust estimation.

1. Extreme value theory [1]

This work on the extreme value theory concerned the form of the distribution of the maximum under particular "tail assumptions for the underlying distribution, and in the presence of a trend, to be reported as [1].

2. Robust Estimation

A new class of estimates were introduced for linear and nonlinear regression models that combines the robustness features of both L–moments and M–estimates. A proof of their asymptotic normality was developed and confidence regions derived for the regression parameters. This work was reported in [2].

References

[1] C.S. Withers, Expansions for the distribution of the maximum from distributions with an asymptotically gamma tail when a trend is present, UNC Center for Stochastic Processes Technical Report, to appear.

[2] C.S. Withers, Moment M-estimates in linear and non–linear regression, UNC Statistics Department Mimeo Series No. 2324, July 1994.

WEI WU

Professor Wei Wu of the Statistics Department of the University of Illinois (a former Ph.D. student here) visited the Center for one month and completed jointly with S. Cambanis and E. Carlstein an extensive revision of part of her dissertation by strengthening the basic result and simplifying its proof.

Bootstrapping the sample mean for data with infinite variance. [1]

When data come from a distribution belonging to the domain of attraction of a stable law, Athreya (1987) showed that the bootstrapped sample mean has a random limiting distribution, implying that the naive bootstrap could fail in the heavy-tailed case. The goal here is to classify all possible limiting distributions of the bootstrapped sample mean when the sample comes from a distribution with infinite variance, allowing the broadest possible setting for the (nonrandom) scaling, the resample size, and the mode of convergence (in law). The limiting distributions turn out to be infinitely divisible with possibly random Lévy measure, depending on the resample size. An averaged-bootstrap algorithm is then introduced which eliminates any randomness in the limiting distribution; the averaged-bootstrap converges to the correct (stable) limit in the case of heavy-tailed stable data, provided that appropriate sample-based adjustments have been made for the scale and skewness.

References

[1] W. Wu, E. Carlstein and S. Cambanis, Bootstrapping the sample mean for data with infinite variance, UNC Center for Stochastic Processes Technical Report No. 296, revised Nov. 93.

JIE XIONG

Professor Jie Xiong (a former student here) spent a postdoctoral year at the Mathematics Department of UNC-Charlotte in 1992-93 and visited the Center for three months (June - August 1993), before joining the Mathematics Department of the University of Tennessee in Knoxville. He worked jointly with G. Kallianpur in various aspects of infinite dimensional stochastic differential equations and their applications. This work has been included in the description of Kallianpur's work. He also spent June 1994 at the Center.

1. (with G. Kallianpur) Diffusion approximation of nuclear space-valued stochastic differential equations driven by Poisson random measures. [1]

This work has been included in the description of Kallianpur's work.

2. (with G. Kallianpur) Stochastic differential equations in infinite dimensions: A brief survey and some new directions of research. [2]

This work has been included in the description of Kallianpur's work.

3. (with Bhatt, Kallianpur and Karandikar) Hilbert space valued diffusions. [3]

This work has been included in the description of Kallianpur's work.

4. (with G. Kallianpur) Stochastic models of environmental pollution. [4]

This work has been included in the description of Kallianpur's work.

5. (with G. Kallianpur) Asymptotic behavior of a system of interacting nuclear-space-valued stochastic differential equations driven by Poisson random measures. [5]

This work has been included in the description of Kallianpur's work.

6. Large deviations for diffusion processes in duals of nuclear spaces. [6]

Motivated by application to neurophysiological problems, various authors have studied diffusion processes in duals of countably Hilbertian nuclear spaces governed by stochastic differential equations. In these models, the diffusion coefficients describe the random stimuli received by spatially extended neurons. In this paper, Xiong presents a large deviation principle for such processes when the diffusion terms tend to zero in terms of a small parameter. The lower bounds are established by making use of the Girsanov formula in abstract Wiener space. The upper bounds are obtained by Gaussian approximation of the diffusion processes and by taking advantage of the nuclear structure of the state space to pass from compact sets to closed sets. The topic has led to further collaboration with G. Kallianpur.

7. (with G. Kallianpur) Large deviations for a class of stochastic reaction–diffusion equations. [7]

This work has been included in the description of Kallianpur's work.

References

[1] G. Kallianpur and J. Xiong, Diffusion approximation of nuclear space-valued stochastic differential equations driven by Poisson random measures, UNC Center for Stochastic Processes Technical Report No. 399, July 1993, submitted for publication.

[2] G. Kallianpur and J. Xiong, Stochastic differential equations in infinite dimensions: A brief survey and some new directions of research, *Multivariate Analysis: Future Directions*, ed. C.R. Rao, North Holland Series in Statistics and Probability, **5**, 267-277 (1993).

[3] A.G. Bhatt, G. Kallianpur, R.L. Karandikar and J. Xiong, Hilbert space valued diffusions, *Applied Mathematics and Optimization*, to appear.

[4] G. Kallianpur and J. Xiong, Stochastic models of environmental pollution, *Advances in Applied Probability*, to appear.

[5] G. Kallianpur and J. Xiong, Asymptotic behavior of a system of interacting nuclear-space-valued stochastic differential equations driven by Poisson random measures, UNC Center for Stochastic Processes Technical Report No. 393, June 93.

[6] J. Xiong, Large deviations for diffusion processes in duals of nuclear spacs, UNC Center for Stochastic Processes Technical Report No. 443, July 94. To appear in *Appl. Math. Optimization.*

[7] G. Kallianpur and J. Xiong, Large deviations for a class of stochastic reaction-diffusion equations, UNC Center for Stochastic Processes Technical Report No. 444, July 94.

PH.D. STUDENTS

PH.D. DEGREES AWARDED

JIE XIONG (April 1992)
G. Kallianpur, advisor

Nuclear space-valued stochastic differential equations driven by Poisson random measures

DAVE BALDWIN (May 1992)
G. Kallianpur, advisor

Topics in the theory of stochastic processes taking values in the dual of a countably Hilbertian nuclear space

AMARJIT BUDHIRAJA (May 1994)
G. Kallianpur, advisor

Multiple stochastic integrals and Hilbert space valued traces with applications to asymptotic statistics and non-linear filtering

EXPECTED PH.D. DEGREES

YOON-TAI KIM (expected 1995-96)
G. Kallianpur, advisor

Kim's thesis is on "Parameter estimation in stochastic partial differential equations and Wong–Zakai theorems in stochastic partial differential equations" under the direction of G. Kallianpur and will consist of two parts: (a) Parameter estimation in stochastic partial differential equations, (b) Wong-Zakai type results for stochastic differential equations in infinite dimensions.

PARANAB MANDAL (expected 1996-97)
G. Kallianpur, advisor

He is still reading in such areas as delayed stochastic differential equations.

AMITES DASGUPTA
G. Kallianpur, advisor

Dasgupta has just started his dissertation research in a wide range of problems involving stable and other infinitely divisible processes under the direction of S. Cambanis, who died on April 12, 1995, and is expected to complete his research under G. Kallianpur.

JOURNAL PUBLICATIONS

1. J.M.P. Albin, On the general law of iterated logarithm with application to Gaussian processes in $\mathbf{R}^n$ and Hilbert space and to stable processes. *Stochastic Proc. Appl.*, **41**, 1992, 1-31.

2. J.M.P. Albin, On the upper and lower classes for stationary Gaussian stochastic processes, *Ann. Probability*, **22**, 1994, 77-93.

3. K. Benhenni and S. Cambanis, Sampling designs for estimating integrals of stochastic processes, *Ann. Statist.*, **20**, 1992, 161-194.

4. K. Benhenni and S. Cambanis, Sampling designs for estimating integrals of stochastic processes using quadratic mean derivatives, *Approximation Theory*, G. Anastassiou, ed., M. Dekker, 1992, 93-123.

5. P. Bloomfield, H.L. Hurd and R. Lund, Periodic correlation in stratospheric ozone data, *J. Time Series Anal.*, **15**, 1994, 127-150.

6. R.C. Bradley, Equivalent mixing conditions for random fields, *Ann. Probability*, **21**, 1993, 1921-1926.

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Articles Submitted

110. S. Bobkov, Isoperimetric problem for uniform enlargement.

111. W. Bryc and W. Smolenski, A sensitivity estimate for Boolean functions.

112. A. Budhiraja and G. Kallianpur, Multiple Ogawa integrals, multiple Stratonovich integrals and a generalized Hu-Meyer formula.

113. S. Cambanis and I. Fakhre-Zakeri, Forward and reversed time prediction of autoregressive sequences.

114. S. Cambanis and Y. Hu, Exact convergence rates of the Euler-Maruyama scheme, with applications to sampling design.

115. A. Deis and H. Rootzén, A k-sample test for proportional hazards with an application to the strength of materials.

116. I. Fakhre-Zakeri and J. Farshidi, Limit theorems for sample covariance of stationary linear processes with applications to sequential estimation.

117. T. Hsing and M.R. Leadbetter, On the excursion random measure of stationary processes.

118. Y.-Z. Hu and V. Perez-Abreu, A note on the continuity of Wiener chaos.

119. G. Kallianpur and V.G. Papanicolaou, Integration over Hilbert spaces: examples inspired by the harmonic oscillator.

120. G. Kallianpur and C. Tudor, Almost periodically distributed solutions for diffusion equations in duals of nuclear spaces.

121. M.R. Leadbetter and T. Hsing, On multiple-level excursions by stationary processes with deterministic peaks.

122. R. LePage, A representation theorem for linear functions of random variables with applications to option pricing.

123. R. LePage and K. Podgorski, A non linear solution of inverse problems.

124. R. LePage, K. Podgorski and M. Ryznar, Strong and conditional invariance principles for samples attracted to stable laws.

125. H. Li, M. Scarsini and M. Shaked, Bounds for the distribution of a multivariate sum.

126. H. Li, M. Scarsini and M. Shaked, Linkages: A tool for the construction of multivariate distributions with given nonoverlapping marginals.

127. P. McGill, Brownian motion, matrix factors, and excursions.

128. P. McGill, First exit of a Lévy process from an interval.

129. D. Monrad, Uniform dimension theorem for the sample functions of stable Lévy processes with local times.

130. J. Olsson and H. Rootzén, Quantile estimation in a nonparametric component of variance framework with applications to vision problems.

131. M. Pawlak, Nonparametric estimation of band-limited functions.

132. A. Tartakovsky, Asymptotically optimal sequential tests for nonhomogeneous processes.

133. S.C. Withers, Expansions for the distribution of the maximum from distributions with a power tail when a trend is present.

Stochastic Processes Seminars 1992–1995

Sept. 9, 92	J. Hüsler, University of Bern: *Boundary crossings of Gaussian processes with applications to empirical characteristic functions*
Sept. 16	S.B. Fotopoulos, Washington State University and Center for Stochastic Processes: *Rates of convergence to normality for strictly stationary sequences of random variables*
Sept. 23	T.N. Sriram, The University of Georgia: *Invalidity of bootstrap for critical branching processes with imigration*
Sept. 30	A. Kanniganti, Purdue University and Center for Stochastic Processes: *The frontier of a branching Brownian motion with killing*
Oct. 14	Y. Kifer, Hebrew University and UNC-CH: *Large deviations from the ergodic phenomenon*
Oct. 28	Y. Kifer, Hebrew University and UNC-CH: *(i) Large deviations and averaging for diffusions and (ii) Donsker-Varadhan's formula*
Nov. 4	Y. Kifer, Hebrew University and UNC-CH: *Large deviations in statistical mechanics*
Nov. 11	A.F. Karr, National Institute of Statistical Sciences and UNC-CH: *Estimation of intensity functions of Poisson processes via sieves, with application to positron emission tomography*
Nov. 18	H.L. Hurd, UNC-CH: *The unitary operator of periodically correlated stochastic processes*
Nov. 20	H.L. Hurd, UNC-CH: *Almost periodically correlated processes*
Dec. 2	J. Farshidi, Center for Stochastic Processes: *Autoregressive expansion of linear predictors for second order stationary fields: horizontal, vertical and "southwest" prediction*
Dec. 4	H.L. Hurd, UNC-CH: *Random time shifts of random processes*
Dec. 9	D. Geman, University of Massachusetts and Brown University: *2D object recognition and the 2D questions paradigm*
Dec. 11	H.L. Hurd, UNC-CH: *Periodically perturbed dynamical systems*
Jan. 25, 93	G. Kallianpur, UNC-CH: *Nonlinear transformation of a Wiener measure: absolute continuity and likelihood ratios*
Jan. 27	T. Koski, Lulea University of Technology: *A stochastic Ricker model*

Feb. 10	G. Anastassiou, Memphis State University: *Central limit theorem, weak law of large numbers for martingales in Banach spaces and weak invariance principle – a quantitative study*
Feb. 17	P. McGill, University of California-Irvine and Center for Stochastic Processes: *Brownian motion, matrix factors, and excursions*
Mar. 2	L. Dubins, University of California-Berkeley: *Sharp martingale inequalities*
Mar. 17	J. Beran, University of Zürich: *Limit theorems and statistical inference for long-memory process*
Mar. 24	H. Cohn, University of Melbourne: *Random matrices and multitype branching processes*
Aprl 14	D.J. Daley, Australian National University: *A random walk problem and convergence rates in the strong law for strong mixing stationary sequences*
Apr. 21	C. Houdré, Stanford University: *On covariance identities and inequalities for functions of Gaussian variables*
Apr. 23	J. Rosinski, University of Tennessee, Knoxville: *Structure of stable processes: spectral representation and stationarity*
May 10	J.L. Teugels, University of Leuven: *Extremes in insurance*
May 10	J. Beirlant, University of Leuven: *Extremes and mean residual plots*
May 10	H. Rootzén, University of Lund and Center for Stochastic Processes: *Tail empirical processes*
May 18	K. Inoue, Center for Stochastic Processes and Shinshu University: *Admissible perturbations of processes with independent increments*
May 28	R.B. Lund, UNC-CH: *Time series with periodic correlation*
June 9	M. Pawlak, University of Manitoba and Center for Stochastic Processes: *Recovering band-limited functions under noise*
June 17	H.L. Hurd: *Dynamical systems with cyclostationary orbits*
June 23	D. Bell, University of North Florida: *The Malliavin calculus and infinitely degenerate hypoelliptic operators*
June 24	H. von Weizsaecker, University of Kaiserlautern: *A transformation formula for abstract measures*

July 1	S.B. Bobkov, Syktyvkar State University and Center for Stochastic Processes: *Gaussian oscillation function on convex states*
July 14	P. McGill, University of California - Irvine and Center for Stochastic Processes: *Path properties in supercritical branching*
July 20	R. Pettersson, Lund University and Center for Stochastic Processes: *Approximations for stochastic differential equations with reflecting convex boundaries*
July 27	I. Rychlik, Lund University and Center for Stochastic Processes: *Fatigue failure time distribution under random loading*
Aug. 18	W. Wu, University of Illinois and Center for Stochastic Processes: *M-Estimation for linear regression with infinite variance*
Sept. 1	A. Budhiraja, University of North Carolina : *Multiple Stratonovich integrals, Hilbert space valued traces and applications to asymptotic distributions of V-statistics*
Sept. 8	K. Benhenni, Université Pierre Mendes, France and Center for Stochastic Processes: *Approximations and designs for estimating regression coefficients of independent stochastic processes*
Sept. 15	E. Guerre, Université Paris VI and Center for Stochastic Processes: *The convergence of the Box-Cox procedure: A simplified case*
Sept. 20	P. McGill, University of California, Irvine and Center for Stochastic Processes: *Spatial properties of local time for branching Brownian motion*
Sept. 29	M. Stein, University of Chicago: *Locally lattice sampling designs for isotropic random fields*
Oct. 6	A. Bhatt, ISI, New Delhi and Center for Stochastic Processes: *Invariant measures and evolution equations for Markov processes characterised via Martingale problems*
Oct. 13	B. Grigelionis, Vilnius University, Lithuania and Center for Stochastic Processes : *Conditionally exponential families and Lundberg exponents of Markov additive processes*
Nov. 4	W.A. Woyczynski, Case Western Reserve University: *Stochastic Burgers' flow*
Nov. 4	D. Surgailis, Case Western Reserve University: *Extrema and intermediate asymptotics of statistical solutions of Burgers' equation*
Nov. 10	V. Hösel, GSF - Forschungszentrum für Umwelt und Gesundheit GmbH, Munich: *P_n-weakly stationary processes*

Nov. 17 J.S. Marron, University of North Carolina: *Visual error criteria for qualitative smoothing*

Dec. 1 G.B. Giannakis, University of Virginia: *Higher–order cyclostationarity: some theory and some applications*

Dec. 8 J. Silverstein, NC State University: *Eigenvalues of large dimensional sample covariance matrices*

Jan. 11, 94 T. Hida, Meijo University: *White noise approach to random fields*

Jan. 19 M. Scarsini, Università D'Annunzio, Pescara: *Copulae of probability measures and capacities on product spaces*

Jan. 26 I. Rychlik, University of Lund and Center for Stochastic Processes: *Rainflow method in random processes*

Feb. 2 Constantin Tudor, University of Bucharest and Center for Stochastic Processes: *Periodic and almost periodic solutions for semilinear stochatic equations*

Feb. 9 A.G. Bhatt, ISI, New Delhi and Center for Stochastic Processes: *Uniqueness of solution of the Zakai equation for the non–linear filtering problem*

Mar. 16 W. Bryc, University of Cincinnati and Center for Stochastic Processes: *Conditional moment representations for dependent random variables*

Mar. 24 A. Makagon, Hampton University and Michigan State University: *On the structure of periodically distributed sequences*

Mar. 30 R. LePage, Michigan State University and Center for Stochastic Processes: *Why is pricing an option the same problem as recovering a density or an image?*

Apr. 6 P. McGill, University of California, Irvine and Center for Stochastic Processes: *Upper functions, large deviations, and coupling*

Apr. 7 O.A. Oleinik, Moscow State University and Center for Stochastic Processes: *Asymptotic properties of some nonlinear elliptic equations*

Apr. 12 O.A. Oleinik, Moscow State University and Center for Stochastic Processes: *Some homogenization problems for nonlinear elliptic equations*

Apr. 26 O.A. Oleinik, Moscow State University and Center for Stochastic Processes: *Averaging of differential operators and related probability problems*

Apr. 28	O.A. Oleinik, Moscow State University and Center for Stochastic Processes: *Asymptotic properties of solutions of a class of nonlinear elliptic equations arising in probability theory*
May 11	Y.-Z. Hu, University of Oslo and Center for Stochastic Processes: *Infinite dimensional stochastic differential equations and stochastic quantization*
May 25	A. Budhiraja, Center for Stochastic Processes: *Anticipative stochastic integrals and Hilbert space valued traces*
May 26	V. Hösel, Research Center for Environment and Health, Munich and Center for Stochastic Processes: *Knowledge based methods for medical image interpretation*
June 9	A. Tartakovsky, Mints Inst. of Radio Technology, Moscow and University of California at Los Angeles : *Sequential procedures for detecting change in a nonhomogeneous process*
June 15	V. Perez-Abreu, Math Research Center, Guanajuato : *Covariance identities and inequalities for functionals of a Wiener process*
June 20	R.L. Karandikar, Indian Statistical Institute, New Delhi and Center for Stochatic Processes : *Weak convergence to a Markov process: the Martingale approach*
July 27	A.G. Bhatt, Center for Stochastic Processes: *Robustness of solution of measure valued equations of nonlinear filtering*
Aug. 3	S. Cambanis, University of North Carolina : *Multiresolution of random processes via wavelets: approximation and properties*
Aug. 10	K. Podgorski, Center for Stochastic Processes and Indiana-Purdue University, Indianapolis: *On estimation for a binary channel*
Aug. 31	G. Kallianpur, University of North Carolina : *Differential geometry in statistical inference and stochastic processes*
Sept. 14	G. Kallianpur, University of North Carolina : *Differential geometry in statistical inference and stochastic processes*
Sept. 21	D. Daley, Australian National University and National Inst. for Statistical Science: *Transactional datasets: modelling and inference*
Oct. 5	G.W. Johnson, University of North Carolina and University of Nebraska, Lincoln: *The analytic Feynman integral via additive functionals of Brownian motion*
Oct. 12	V. Hösel, GSF - Forschungszentrum, Munich: *P_n-weakly stationary processes*

Oct. 19 H.L. Hurd, UNC-Chapel Hill: *Periodically correlated random fields on* Z^2

Nov. 2 C. Ji, UNC-Chapel Hill: *Lattice approximation of some Gaussian random fields*

Nov. 9 I. Fakhre-Zakeri, University of Maryland and UNC-Chapel Hill: *Forward and reversed time prediction of autoregressive sequences*

Nov. 17 T. Koski, Lulea University of Technology: *Classification of binary vectors by stochastic complexity*

Nov. 22 C. Houdré, Georgia Institute of Technology : *Some connection between isoperimetry and Sobolev type inequalities*

Dec. 14 A. Mukherjea, University of South Florida: *Invariant measures, random walks, and attractors*

Dec. 12 S. Balaji, Indian Statistical Insitute : *Recurrence and transience of diffusons in the half space*

Dec. 13 Marie Kratz, Université Paris 6: *Parameter estimation for moving averages with positive innovations*

Jan. 18, 95 R.K. Pearson, DuPont Company: *Empirical modeling of chemical manufacturing processes*

Jan. 25 A. Simonian, Yerevan State University : *Reconstruction problems for random processes*

Feb. 8 W. Kliemann, Iowa State University : *Global behavior of dynamical systems*

Feb. 15 A. Simonian, Yerevan State University : *Reconstruction problems for random fields*

Feb. 22 Q.-M. Shao, National University of Singapore: *Self-normalized large deviations and their applications to statistics*

Mar. 3 M. Arcones, University of Utah: *U-statistics, U-processes and applications*

Mar. 6 T. Bielecki, University of Illinois at Chicago: *Adaptive portfolio-consumption selection, option pricing and some Markov modelling*

Mar. 16 O. Kallenberg, Auburn University : *On functional solutions to classical SDE's*

Mar. 30 J. Stoyanov, Miami University, OH: *Asymptotic analysis of per-*

turbed stochastic systems

Apr. 6	A.M. Yaglom, Massachusetts Inst. of Technology : *Some models of stochastic processes and fields originating in the mechanics of turbulent flows*
Apr. 12	A.R. Gallant, University of North Carolina : *Estimating stochastic differential equations efficiently by minimum chi–square*
Apr. 26	J. Farshidi, University of Arizona and Center for Stochastic Processes : *Prediction of stationary second order random fields based on southwest pasts; spectral characterization and AR–expansion*
May 9	C. Ji, University of North Carolina: *Computational complexity of certain Markov chain Monte Carlo algorithms*
June 7, 95	P. McGill, University of California, Irvine and University of North Carolina : *Wave equation as a Hamiltonian system in infinite dimensions*

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